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(12) **United States Patent**
Minagawa et al.

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(45) **Date of Patent: Aug. 2, 2016**

(54) **INFORMATION PROCESSING APPARATUS AND COMPUTER-READABLE STORAGE MEDIUM STORING PROGRAM FOR INTERPOLATING AN INPUT COLOR**

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(73) Assignee: **FUJITSU LIMITED**, Kawasaki (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 71 days.

(21) Appl. No.: **14/601,447**

(22) Filed: **Jan. 21, 2015**

(65) **Prior Publication Data**

US 2015/0221100 A1 Aug. 6, 2015

(30) **Foreign Application Priority Data**

Feb. 6, 2014 (JP) 2014-020948

(51) **Int. Cl.**
H04N 1/60 (2006.01)

(52) **U.S. Cl.**
CPC ***H04N 1/60*** (2013.01); *H04N 1/6019* (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

(56) **References Cited**

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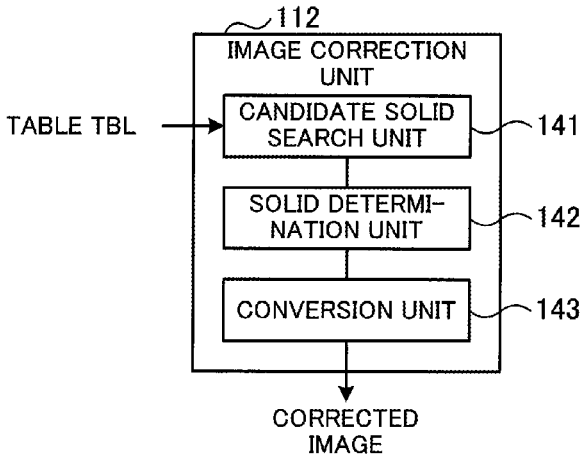
Primary Examiner — Bernard Krasnic
(74) *Attorney, Agent, or Firm* — Fujitsu Patent Center

(57) **ABSTRACT**

An information processing apparatus includes: a storage unit that stores a table including information on regions respectively occupied by a plurality of solids whose vertices are defined by a plurality of reference colors that are set in a color space, each of the solids having an evaluation value less than a setting value, the evaluation value decreasing as the length of edges thereof decreases, the solids being arranged such that faces thereof do not cross each other; and a computing unit that specifies a solid containing an input color with use of the table, and performs interpolation processing of the input color with use of the reference colors corresponding to the vertices of the specified solid.

7 Claims, 30 Drawing Sheets



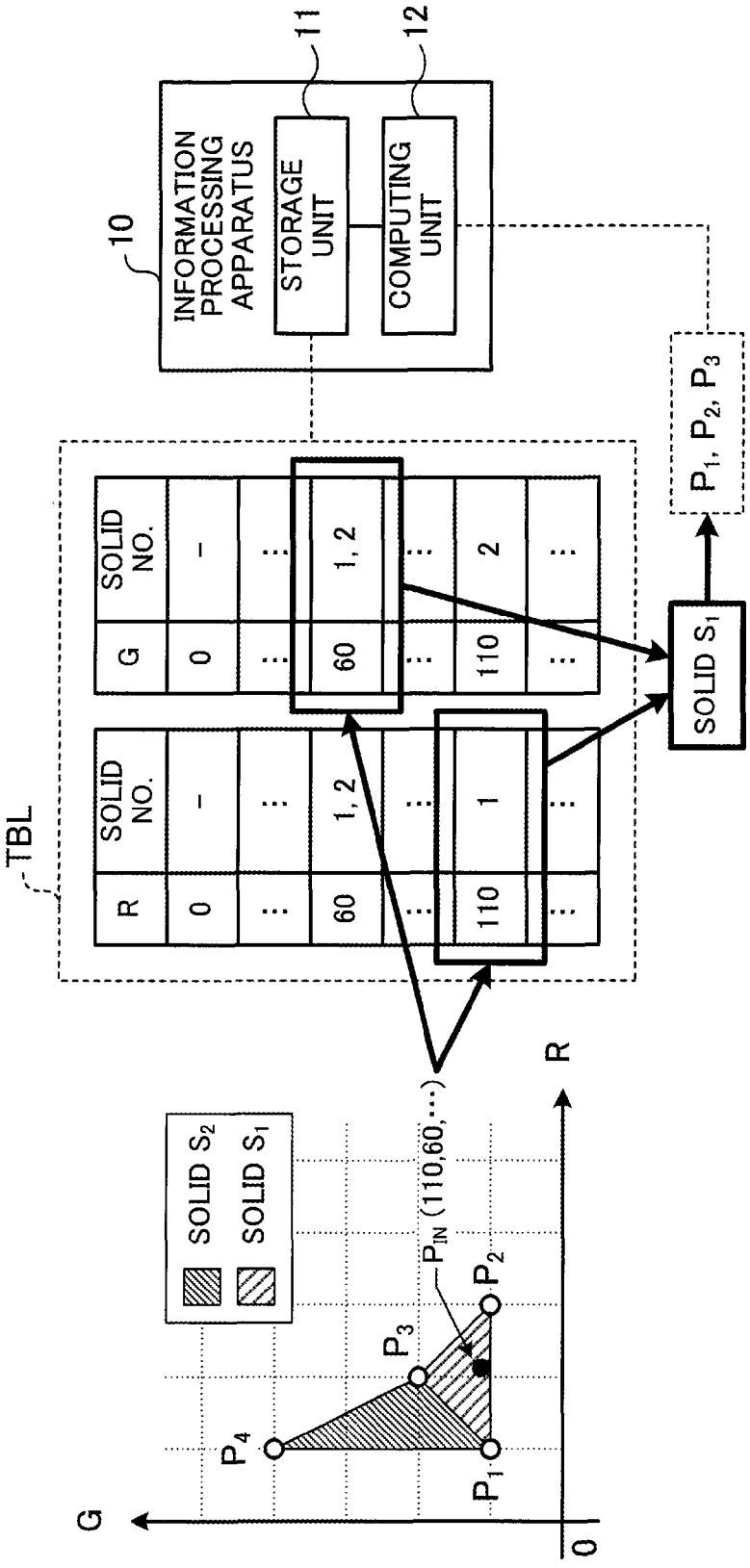

10
INFORMATION PROCESSING APPARATUS
11
STORAGE UNIT
12
COMPUTING UNIT
TBL
R
SOLID NO.
0
–
60
1, 2
110
1
2
G
SOLID S1
P1, P2, P3
SOLID S2
SOLID S1
PIN (110,60,...)
P1
P2
P3
P4
G
R
0

FIG. 1

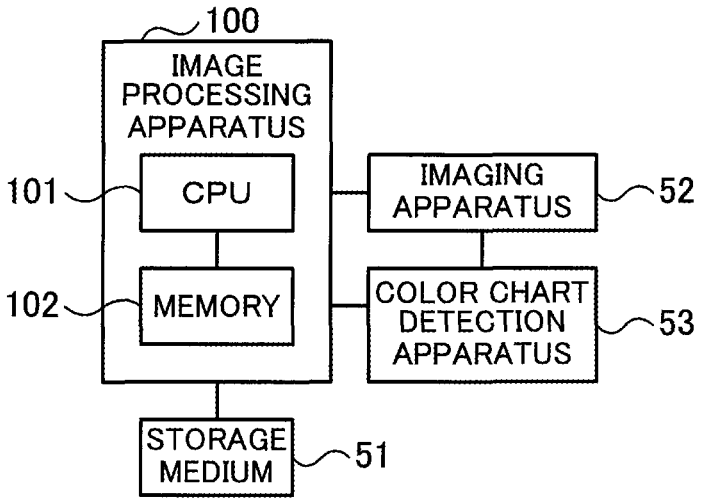

100
IMAGE PROCESSING APPARATUS
101
CPU
102
MEMORY
IMAGING APPARATUS
52
COLOR CHART DETECTION APPARATUS
53
STORAGE MEDIUM
51

FIG. 2

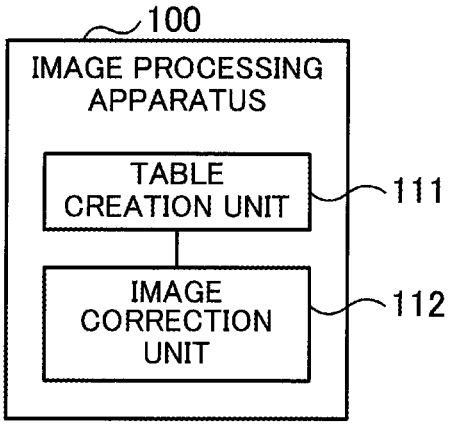

100
IMAGE PROCESSING APPARATUS
TABLE CREATION UNIT
111
IMAGE CORRECTION UNIT
112

FIG. 3

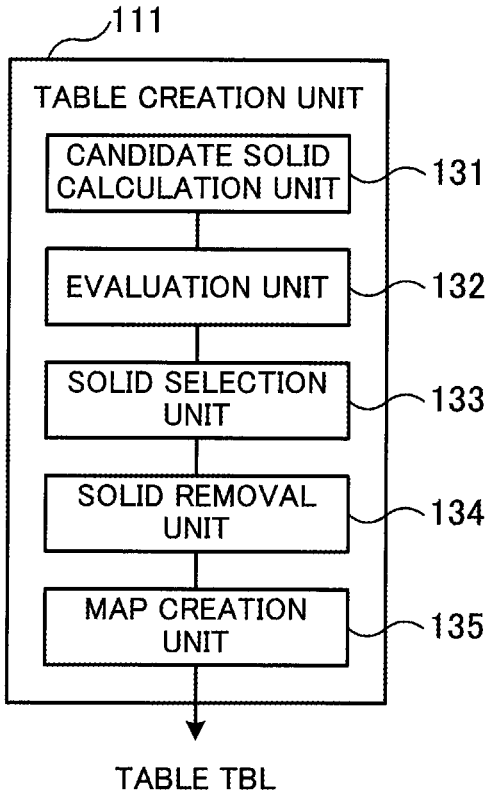

111
TABLE CREATION UNIT
CANDIDATE SOLID CALCULATION UNIT
131
EVALUATION UNIT
132
SOLID SELECTION UNIT
133
SOLID REMOVAL UNIT
134
MAP CREATION UNIT
135
TABLE TBL

FIG. 4

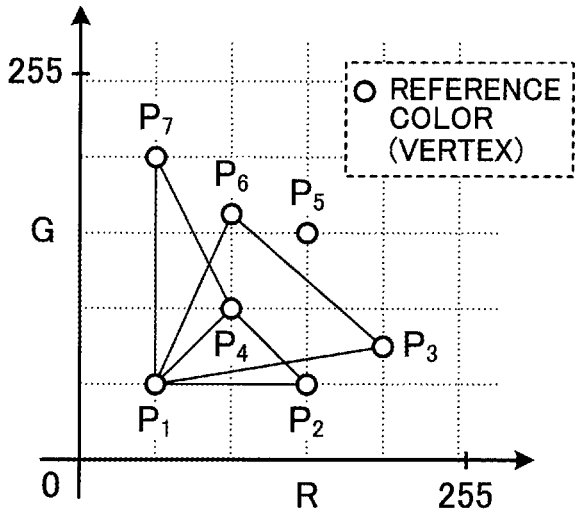


FIG. 5

SOLID NUMBER LIST: CORRESPONDENCE BETWEEN COORDINATES AND SOLID

R	G	B	SOLID NO.
60	50	···	1
60	50	···	3
60	70	···	2
60	70	···	3
⋮	⋮	⋮	⋮

TWO SOLIDS CONTAIN SAME COORDINATES

TWO SOLIDS CONTAIN SAME COORDINATES

FIG. 6

COORDINATE LIST: COORDINATES OF VERTEX

VERTEX NO.	R	G	B
1	50	50	···
2	150	50	···
3	200	80	···
4	100	100	···
5	150	150	···
6	100	160	···
7	50	200	···
⋮	⋮	⋮	⋮

FIG. 7

VERTEX LIST: CORRESPONDENCE BETWEEN SOLID AND VERTICES

SOLID NO.	VERTEX 1	VERTEX 2	VERTEX 3	VERTEX 4
1	1	2	4	...
2	1	4	7	...
3	1	3	6	...
⋮	⋮	⋮	⋮	⋮

FIG. 8

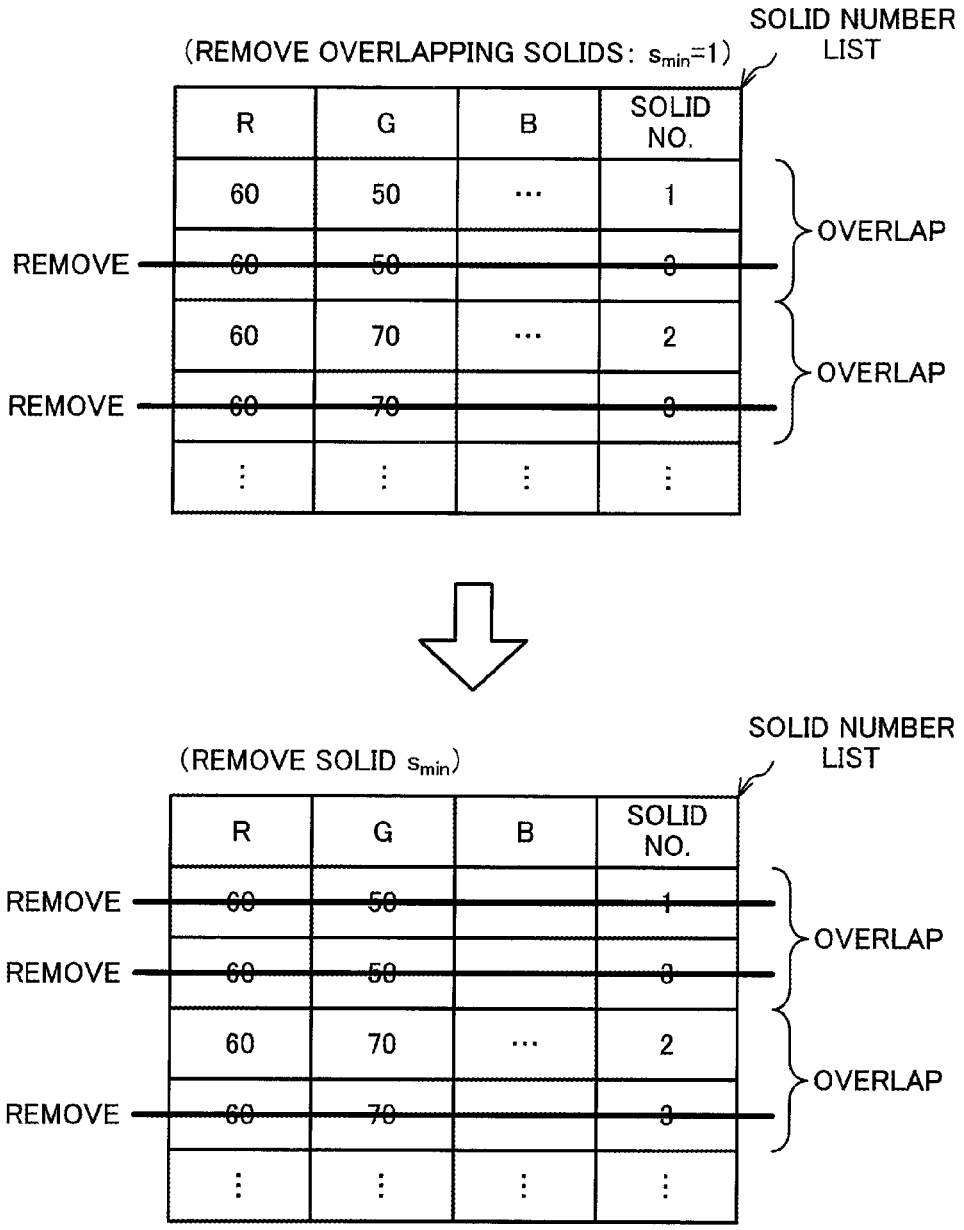
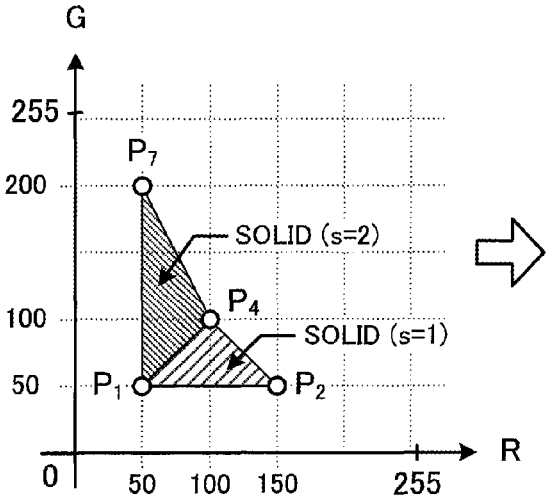

(REMOVE OVERLAPPING SOLIDS: s_{min}=1)
SOLID NUMBER LIST
R
G
B
SOLID NO.
60
50
…
1
REMOVE
60
50
1
OVERLAP
60
70
…
2
REMOVE
60
70
2
OVERLAP
(REMOVE SOLID s_{min})
SOLID NUMBER LIST
R
G
B
SOLID NO.
REMOVE
60
50
1
REMOVE
60
50
1
OVERLAP
60
70
…
2
REMOVE
60
70
2
OVERLAP

FIG. 9



(TABLE TBL)

R	SOLID NO. (MP_R)	G	SOLID NO. (MP_G)
0	–	0	–
1	–	1	–
⋮	⋮	⋮	⋮
49	–	49	–
50	1, 2	50	1, 2
⋮	⋮	⋮	⋮
100	1, 2	60	1, 2
101	1	⋮	⋮
⋮	⋮	100	1, 2
110	1	101	2
⋮	⋮	⋮	⋮
150	1	200	2
151	–	201	–
⋮	⋮	⋮	⋮

FIG. 10

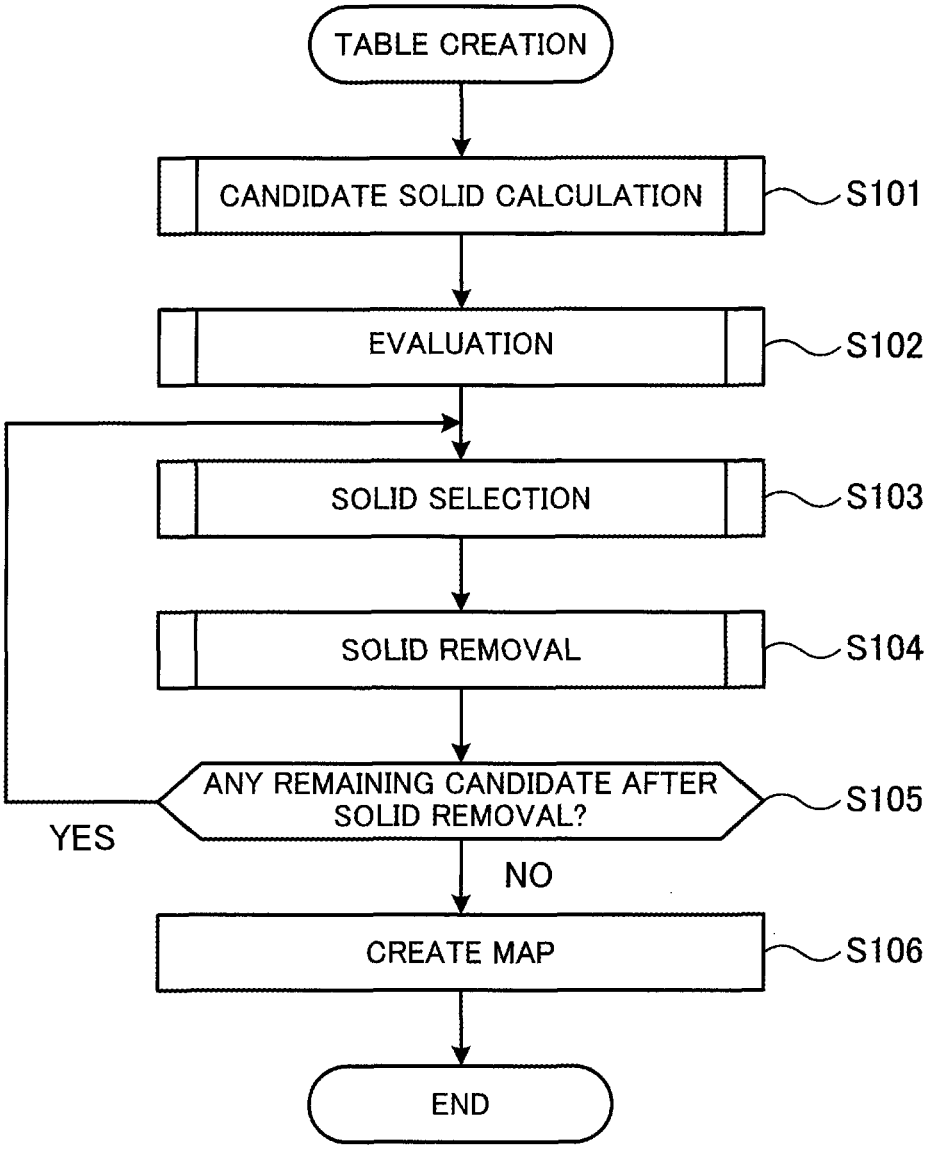


TABLE CREATION
CANDIDATE SOLID CALCULATION
S101
EVALUATION
S102
SOLID SELECTION
S103
SOLID REMOVAL
S104
ANY REMAINING CANDIDATE AFTER SOLID REMOVAL?
S105
YES
NO
CREATE MAP
S106
END

FIG. 11

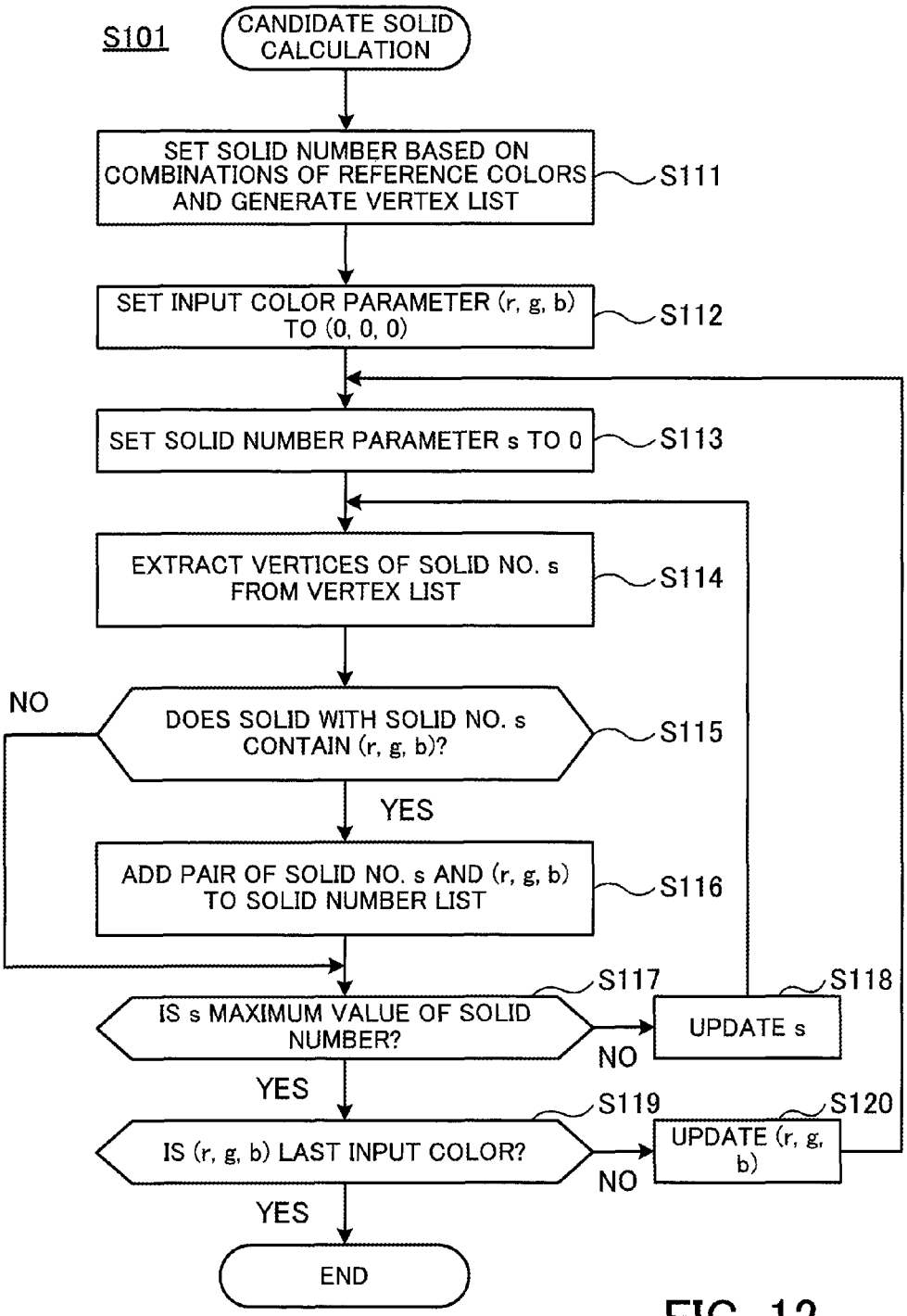

S101
CANDIDATE SOLID CALCULATION
SET SOLID NUMBER BASED ON COMBINATIONS OF REFERENCE COLORS AND GENERATE VERTEX LIST
S111
SET INPUT COLOR PARAMETER (r, g, b) TO (0, 0, 0)
S112
SET SOLID NUMBER PARAMETER s TO 0
S113
EXTRACT VERTICES OF SOLID NO. s FROM VERTEX LIST
S114
NO
DOES SOLID WITH SOLID NO. s CONTAIN (r, g, b)?
S115
YES
ADD PAIR OF SOLID NO. s AND (r, g, b) TO SOLID NUMBER LIST
S116
S117
IS s MAXIMUM VALUE OF SOLID NUMBER?
S118
UPDATE s
NO
YES
S119
IS (r, g, b) LAST INPUT COLOR?
S120
UPDATE (r, g, b)
NO
YES
END

FIG. 12

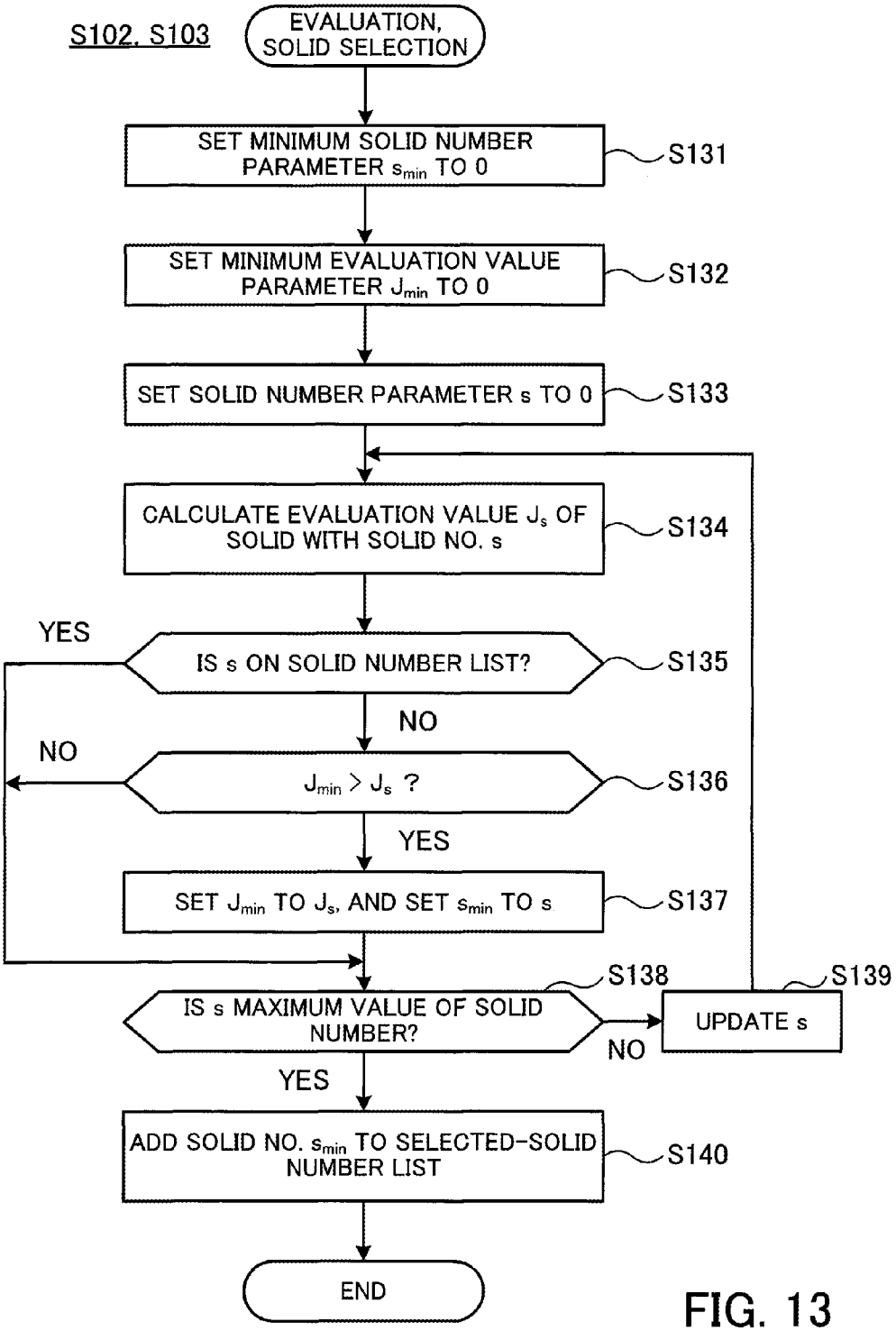

S102, S103
EVALUATION, SOLID SELECTION
SET MINIMUM SOLID NUMBER PARAMETER s_{min} TO 0
S131
SET MINIMUM EVALUATION VALUE PARAMETER J_{min} TO 0
S132
SET SOLID NUMBER PARAMETER s TO 0
S133
CALCULATE EVALUATION VALUE J_s OF SOLID WITH SOLID NO. s
S134
YES
IS s ON SOLID NUMBER LIST?
S135
NO
NO
$J_{min} > J_s$?
S136
YES
SET J_{min} TO J_s, AND SET s_{min} TO s
S137
S138
IS s MAXIMUM VALUE OF SOLID NUMBER?
NO
S139
UPDATE s
YES
ADD SOLID NO. s_{min} TO SELECTED-SOLID NUMBER LIST
S140
END

FIG. 13

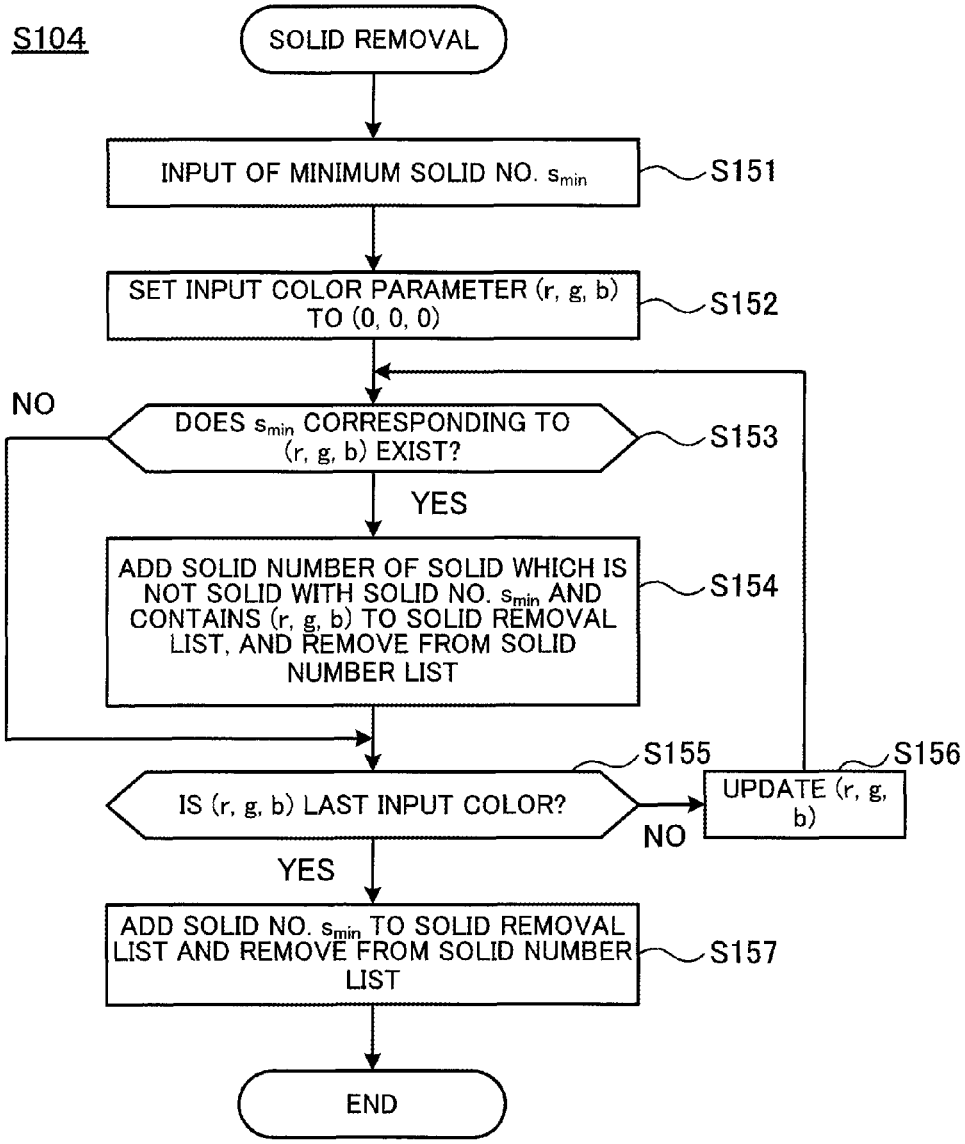

S104
SOLID REMOVAL
INPUT OF MINIMUM SOLID NO. s_{min}
S151
SET INPUT COLOR PARAMETER (r, g, b) TO (0, 0, 0)
S152
NO
DOES s_{min} CORRESPONDING TO (r, g, b) EXIST?
S153
YES
ADD SOLID NUMBER OF SOLID WHICH IS NOT SOLID WITH SOLID NO. s_{min} AND CONTAINS (r, g, b) TO SOLID REMOVAL LIST, AND REMOVE FROM SOLID NUMBER LIST
S154
S155
S156
IS (r, g, b) LAST INPUT COLOR?
NO
UPDATE (r, g, b)
YES
ADD SOLID NO. s_{min} TO SOLID REMOVAL LIST AND REMOVE FROM SOLID NUMBER LIST
S157
END

FIG. 14

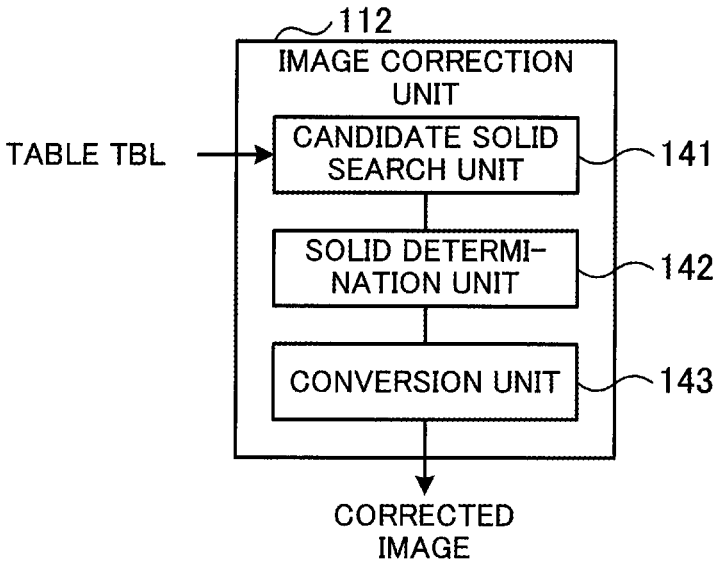
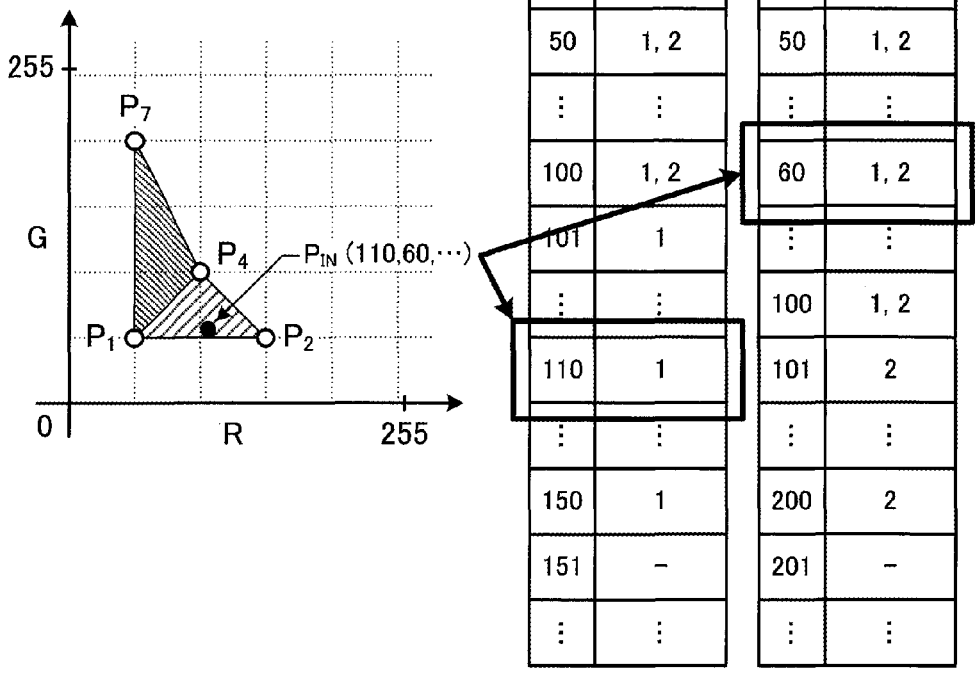

112
IMAGE CORRECTION UNIT
TABLE TBL
CANDIDATE SOLID SEARCH UNIT
141
SOLID DETERMI-NATION UNIT
142
CONVERSION UNIT
143
CORRECTED IMAGE

FIG. 15



R	SOLID NO.
0	–
1	–
⋮	⋮
49	–
50	1, 2
⋮	⋮
100	1, 2
101	1
⋮	⋮
110	1
⋮	⋮
150	1
151	–
⋮	⋮

G	SOLID NO.
0	–
1	–
⋮	⋮
49	–
50	1, 2
⋮	⋮
60	1, 2
⋮	⋮
100	1, 2
101	2
⋮	⋮
200	2
201	–
⋮	⋮

FIG. 16

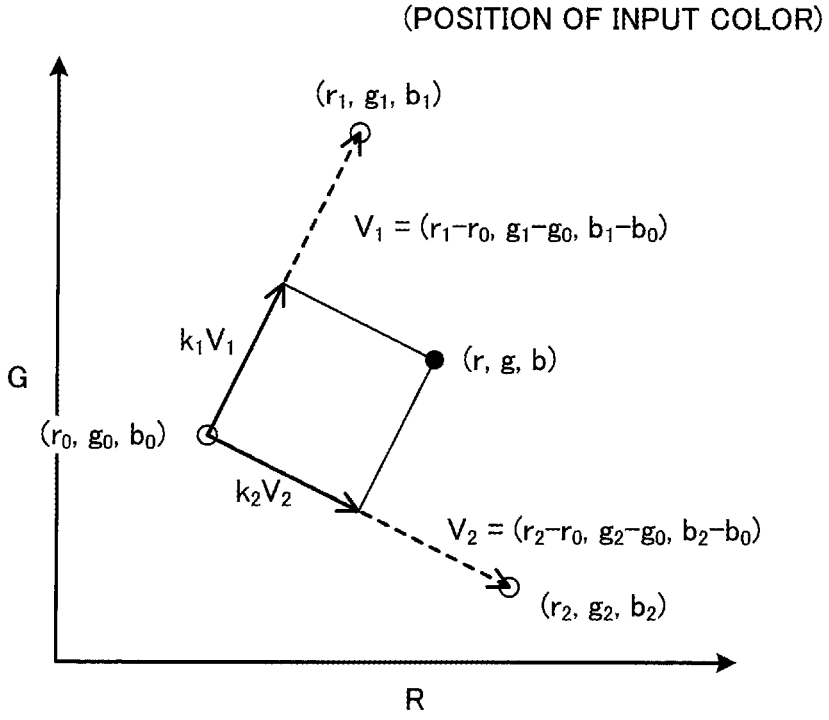

(POSITION OF INPUT COLOR)
(r1, g1, b1)
V1 = (r1−r0, g1−g0, b1−b0)
k1V1
(r, g, b)
G
(r0, g0, b0)
k2V2
V2 = (r2−r0, g2−g0, b2−b0)
(r2, g2, b2)
R

FIG. 17

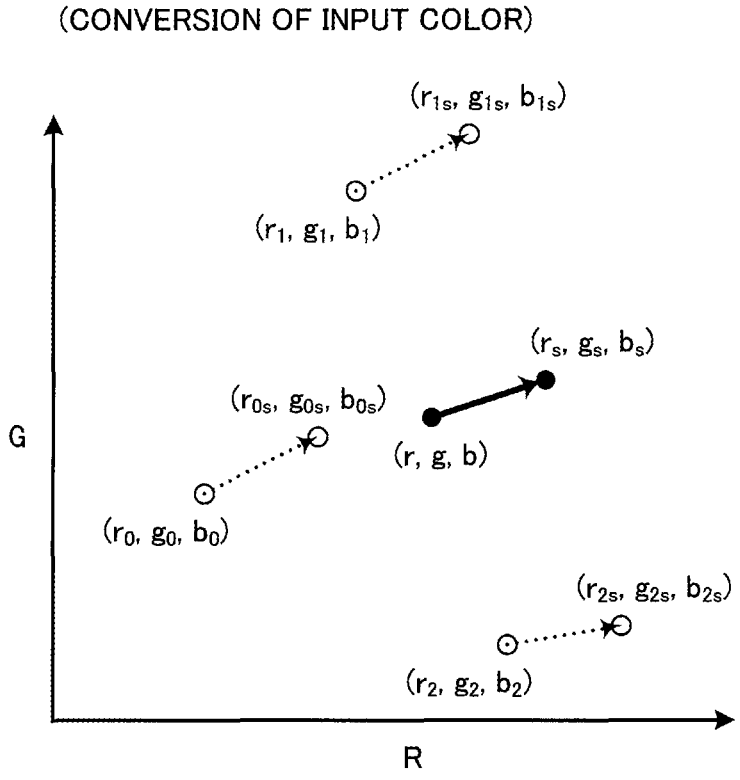

(CONVERSION OF INPUT COLOR)
(r_{1s}, g_{1s}, b_{1s})
(r_1, g_1, b_1)
(r_s, g_s, b_s)
(r_{0s}, g_{0s}, b_{0s})
(r, g, b)
(r_0, g_0, b_0)
(r_{2s}, g_{2s}, b_{2s})
(r_2, g_2, b_2)
G
R

FIG. 18

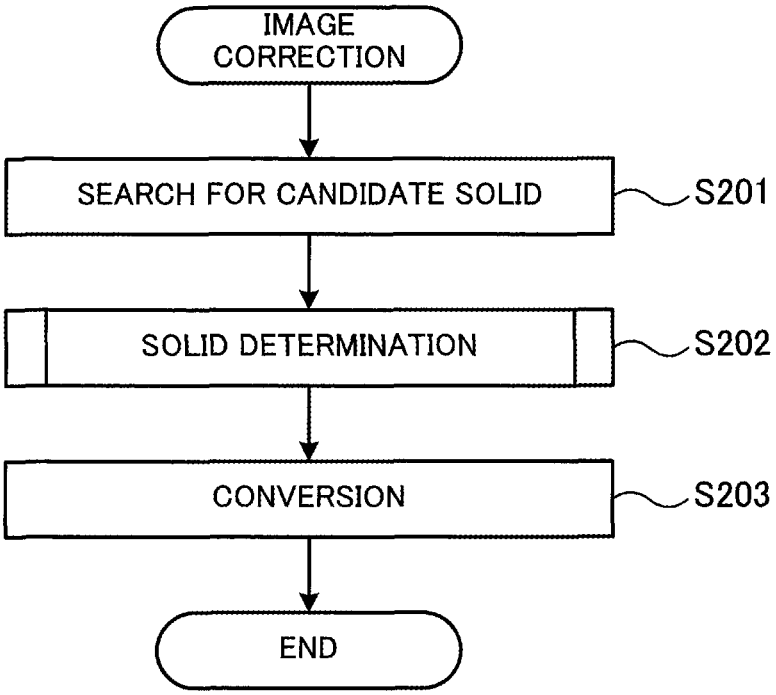


IMAGE CORRECTION
SEARCH FOR CANDIDATE SOLID
S201
SOLID DETERMINATION
S202
CONVERSION
S203
END

FIG. 19

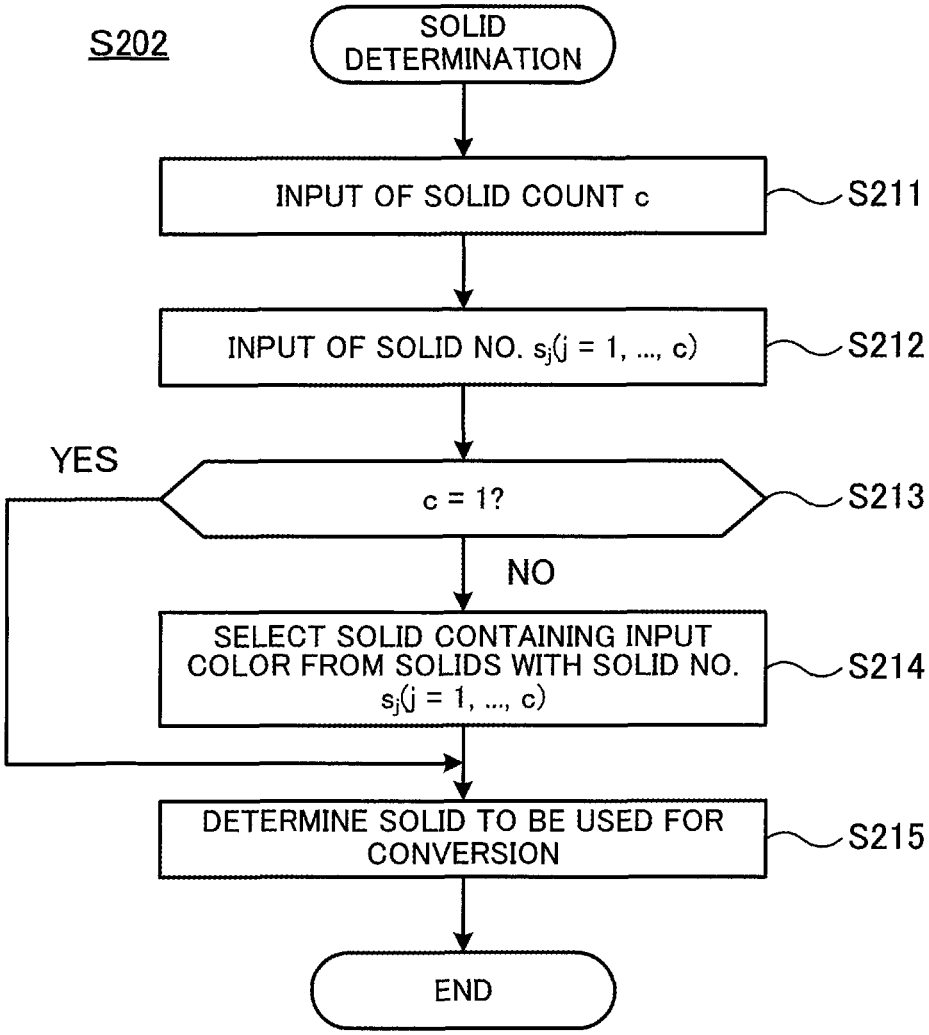

S202
SOLID DETERMINATION
INPUT OF SOLID COUNT c
S211
INPUT OF SOLID NO. s_j(j = 1, ..., c)
S212
YES
c = 1?
S213
NO
SELECT SOLID CONTAINING INPUT COLOR FROM SOLIDS WITH SOLID NO. s_j(j = 1, ..., c)
S214
DETERMINE SOLID TO BE USED FOR CONVERSION
S215
END

FIG. 20

MODIFICATION #1

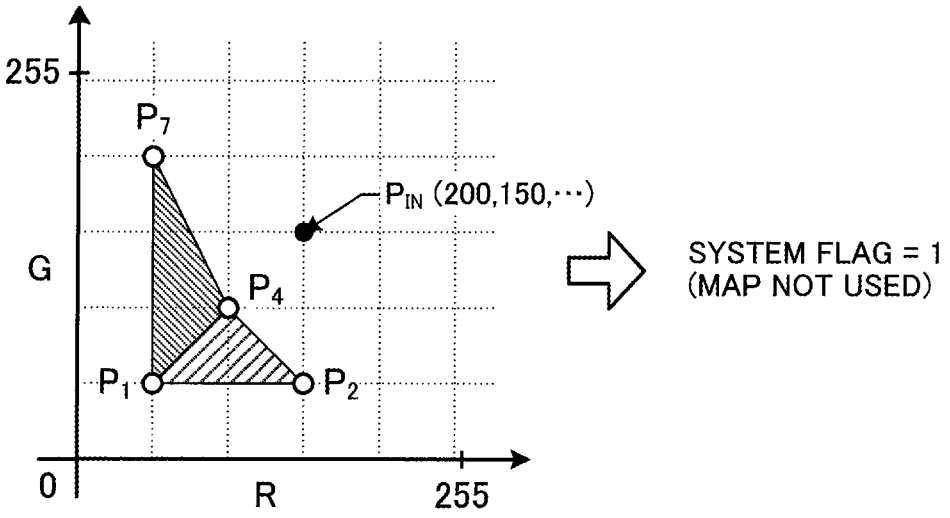


FIG. 21

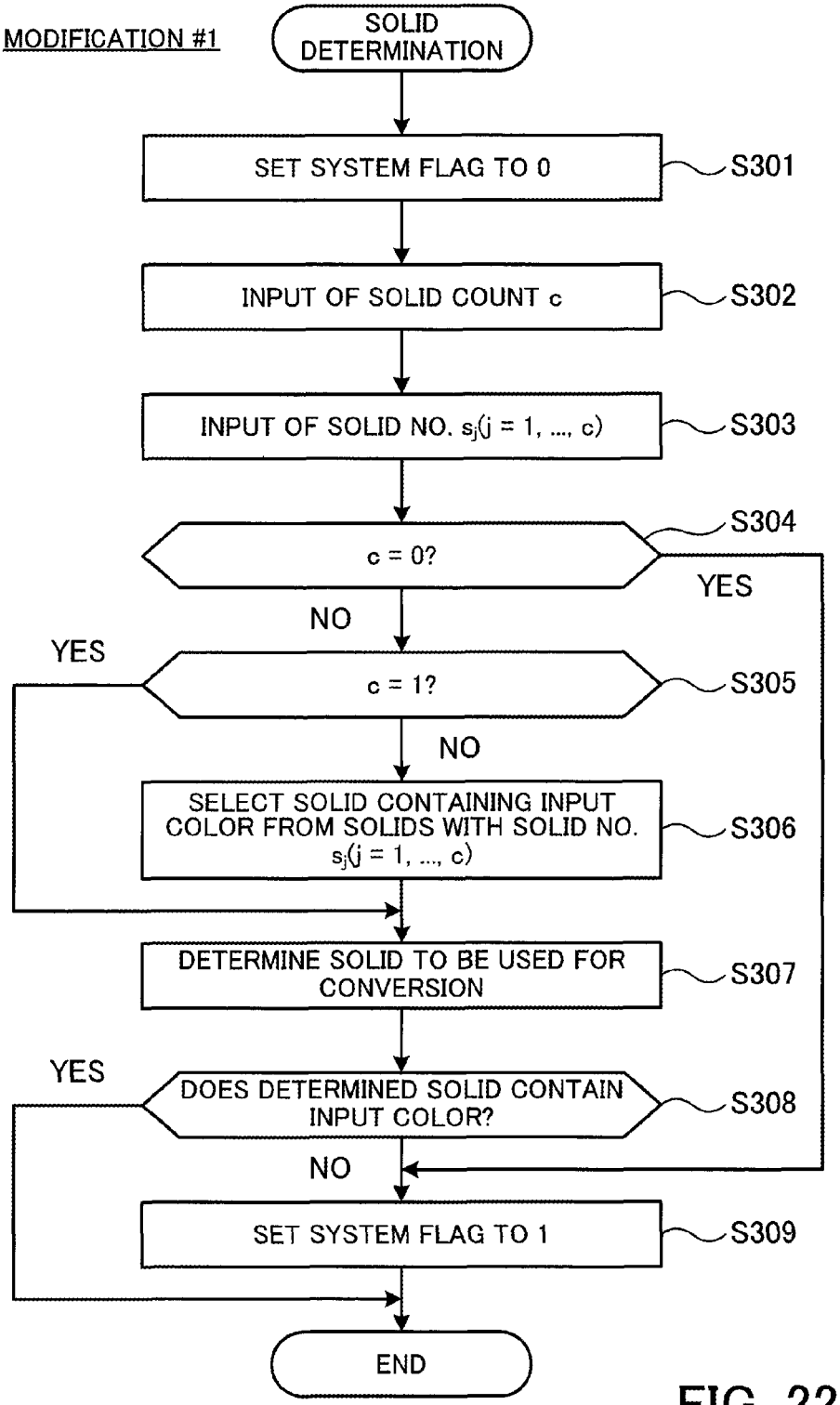

MODIFICATION #1
SOLID DETERMINATION
SET SYSTEM FLAG TO 0
S301
INPUT OF SOLID COUNT c
S302
INPUT OF SOLID NO. s_j(j = 1, ..., c)
S303
c = 0?
S304
YES
NO
YES
c = 1?
S305
NO
SELECT SOLID CONTAINING INPUT COLOR FROM SOLIDS WITH SOLID NO. s_j(j = 1, ..., c)
S306
DETERMINE SOLID TO BE USED FOR CONVERSION
S307
YES
DOES DETERMINED SOLID CONTAIN INPUT COLOR?
S308
NO
SET SYSTEM FLAG TO 1
S309
END

FIG. 22

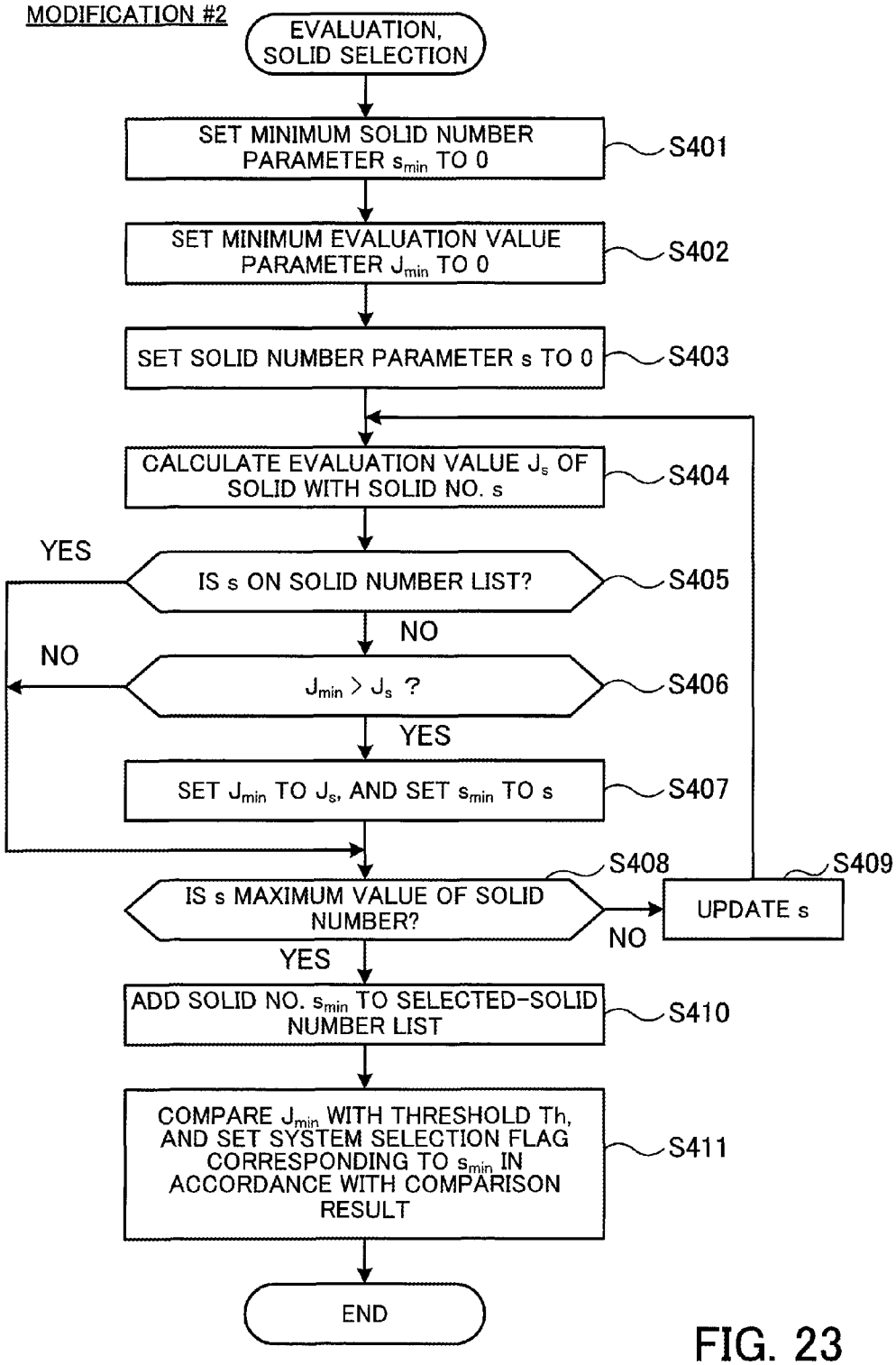

MODIFICATION #2
EVALUATION, SOLID SELECTION
SET MINIMUM SOLID NUMBER PARAMETER s_{min} TO 0
S401
SET MINIMUM EVALUATION VALUE PARAMETER J_{min} TO 0
S402
SET SOLID NUMBER PARAMETER s TO 0
S403
CALCULATE EVALUATION VALUE J_s OF SOLID WITH SOLID NO. s
S404
YES
IS s ON SOLID NUMBER LIST?
S405
NO
NO
$J_{min} > J_s$?
S406
YES
SET J_{min} TO J_s, AND SET s_{min} TO s
S407
S408
IS s MAXIMUM VALUE OF SOLID NUMBER?
S409
UPDATE s
NO
YES
ADD SOLID NO. s_{min} TO SELECTED-SOLID NUMBER LIST
S410
COMPARE J_{min} WITH THRESHOLD Th, AND SET SYSTEM SELECTION FLAG CORRESPONDING TO s_{min} IN ACCORDANCE WITH COMPARISON RESULT
S411
END

FIG. 23

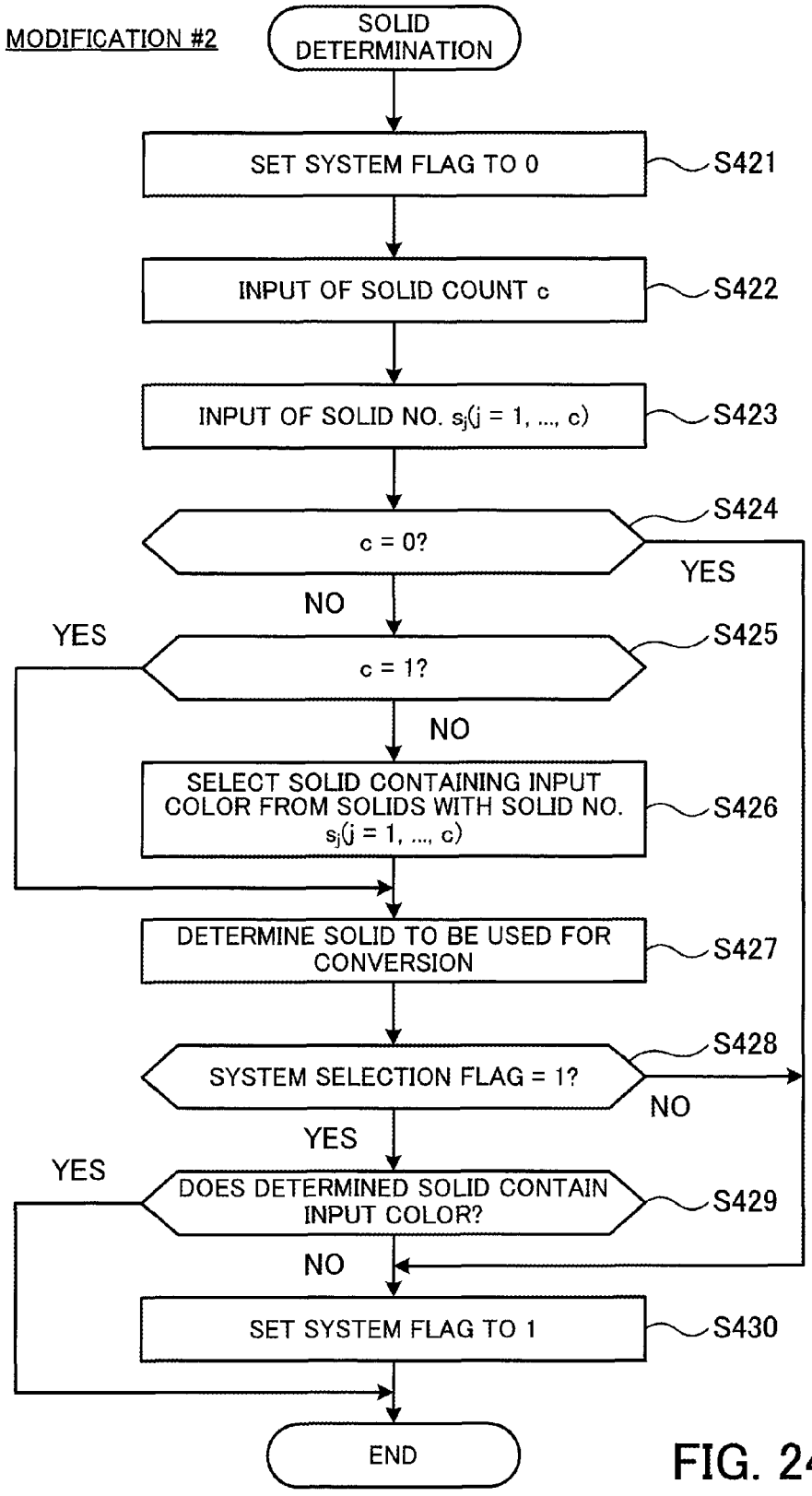

MODIFICATION #2
SOLID DETERMINATION
SET SYSTEM FLAG TO 0
S421
INPUT OF SOLID COUNT c
S422
INPUT OF SOLID NO. s_j(j = 1, ..., c)
S423
c = 0?
S424
YES
NO
YES
c = 1?
S425
NO
SELECT SOLID CONTAINING INPUT COLOR FROM SOLIDS WITH SOLID NO. s_j(j = 1, ..., c)
S426
DETERMINE SOLID TO BE USED FOR CONVERSION
S427
SYSTEM SELECTION FLAG = 1?
S428
NO
YES
YES
DOES DETERMINED SOLID CONTAIN INPUT COLOR?
S429
NO
SET SYSTEM FLAG TO 1
S430
END

FIG. 24

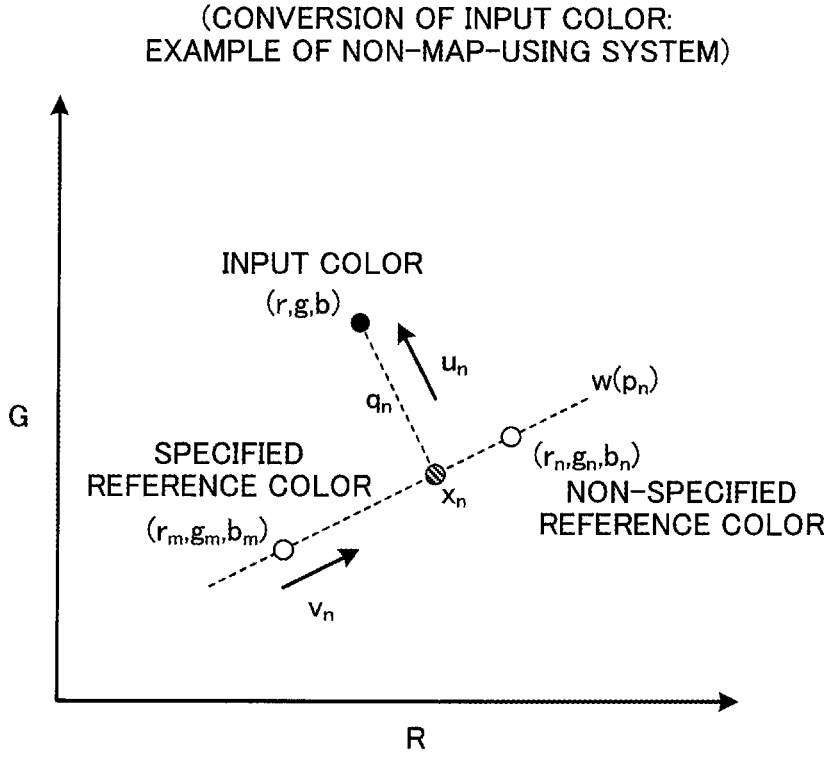

(CONVERSION OF INPUT COLOR:
EXAMPLE OF NON-MAP-USING SYSTEM)
INPUT COLOR
(r,g,b)
u_n
q_n
$w(p_n)$
(r_n,g_n,b_n)
NON-SPECIFIED
REFERENCE COLOR
x_n
SPECIFIED
REFERENCE COLOR
(r_m,g_m,b_m)
v_n
G
R

FIG. 25

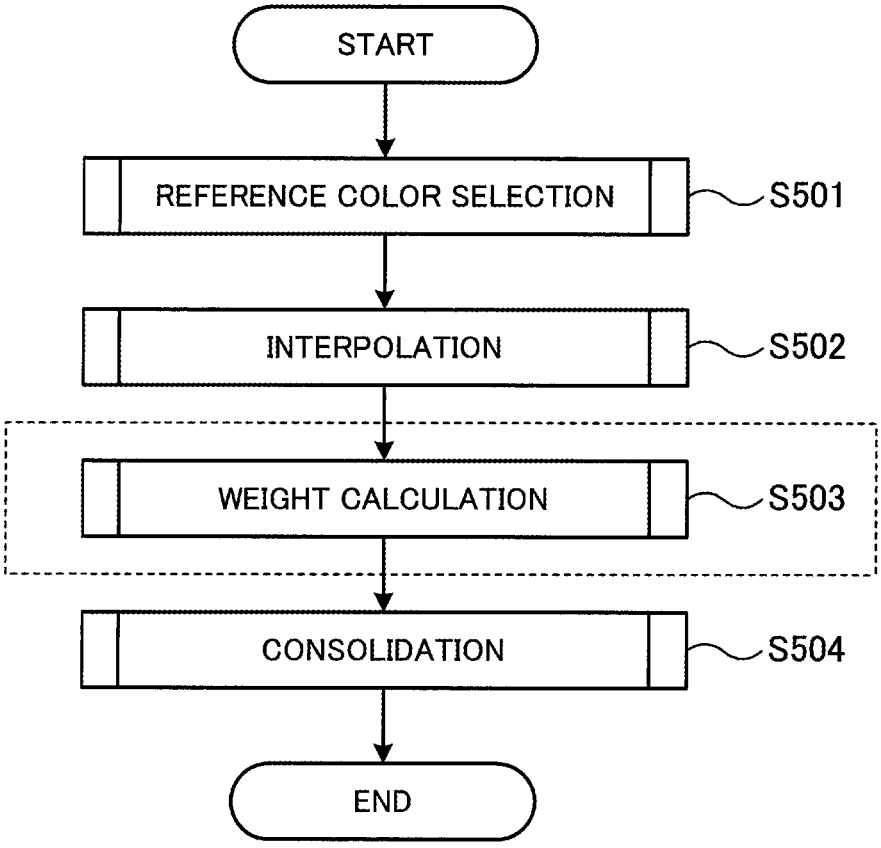

START
REFERENCE COLOR SELECTION
S501
INTERPOLATION
S502
WEIGHT CALCULATION
S503
CONSOLIDATION
S504
END

FIG. 26

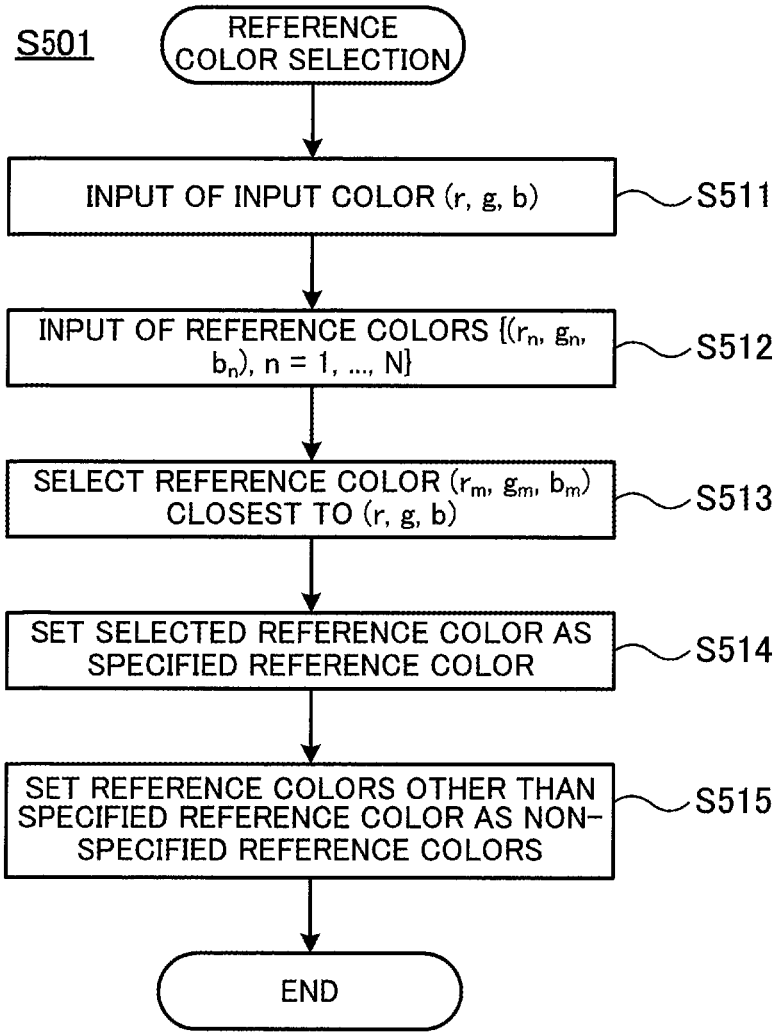

S501
REFERENCE COLOR SELECTION
INPUT OF INPUT COLOR (r, g, b)
S511
INPUT OF REFERENCE COLORS {(r_n, g_n, b_n), n = 1, ..., N}
S512
SELECT REFERENCE COLOR (r_m, g_m, b_m) CLOSEST TO (r, g, b)
S513
SET SELECTED REFERENCE COLOR AS SPECIFIED REFERENCE COLOR
S514
SET REFERENCE COLORS OTHER THAN SPECIFIED REFERENCE COLOR AS NON-SPECIFIED REFERENCE COLORS
S515
END

FIG. 27

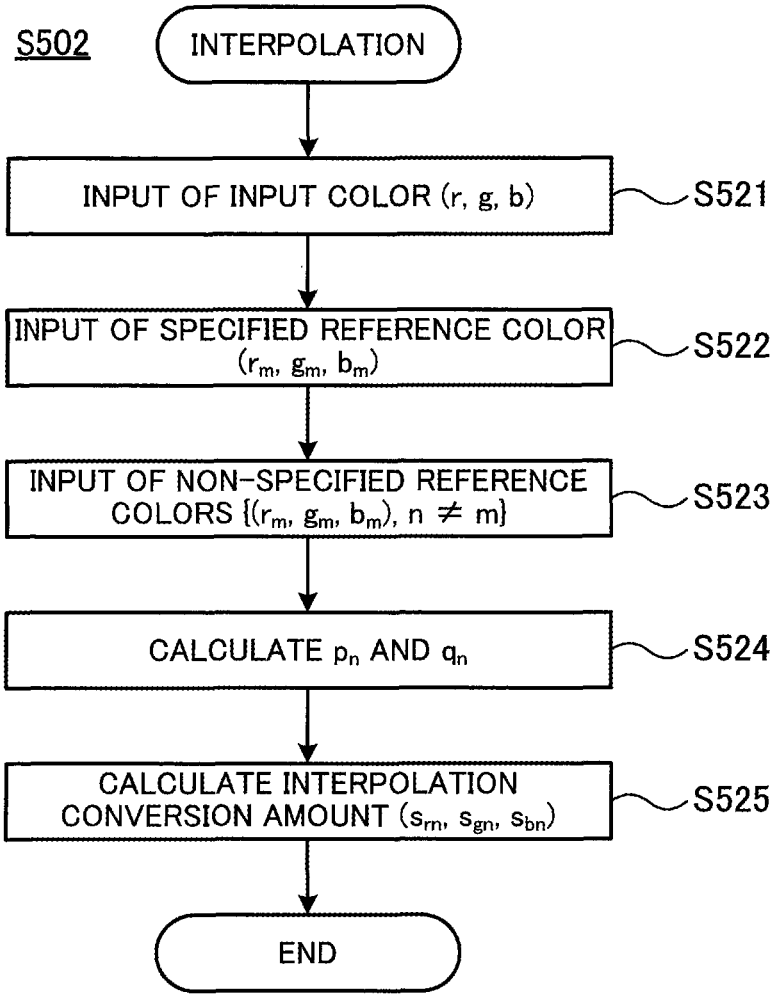

S502
INTERPOLATION
INPUT OF INPUT COLOR (r, g, b)
S521
INPUT OF SPECIFIED REFERENCE COLOR (r_m, g_m, b_m)
S522
INPUT OF NON-SPECIFIED REFERENCE COLORS {(r_m, g_m, b_m), n ≠ m}
S523
CALCULATE p_n AND q_n
S524
CALCULATE INTERPOLATION CONVERSION AMOUNT (s_{rn}, s_{gn}, s_{bn})
S525
END

FIG. 28

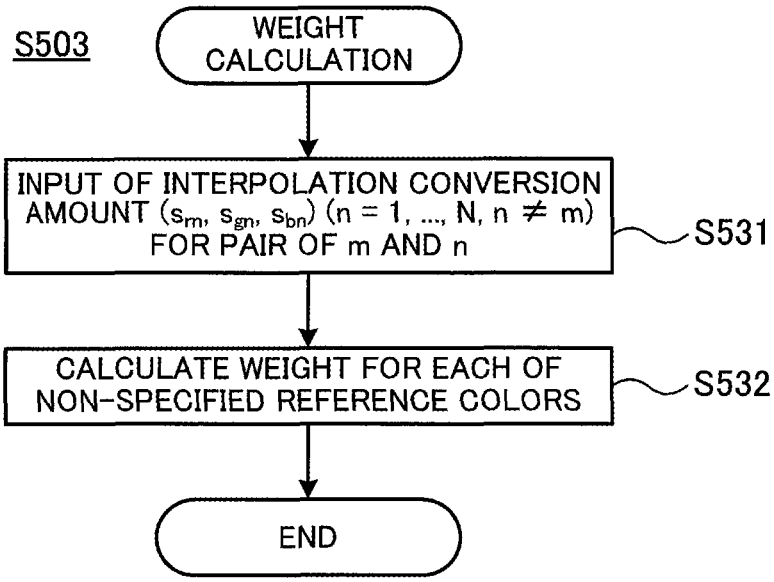

S503
WEIGHT CALCULATION
INPUT OF INTERPOLATION CONVERSION AMOUNT (s_m, s_{gn}, s_{bn}) (n = 1, ..., N, n ≠ m) FOR PAIR OF m AND n
S531
CALCULATE WEIGHT FOR EACH OF NON-SPECIFIED REFERENCE COLORS
S532
END

FIG. 29

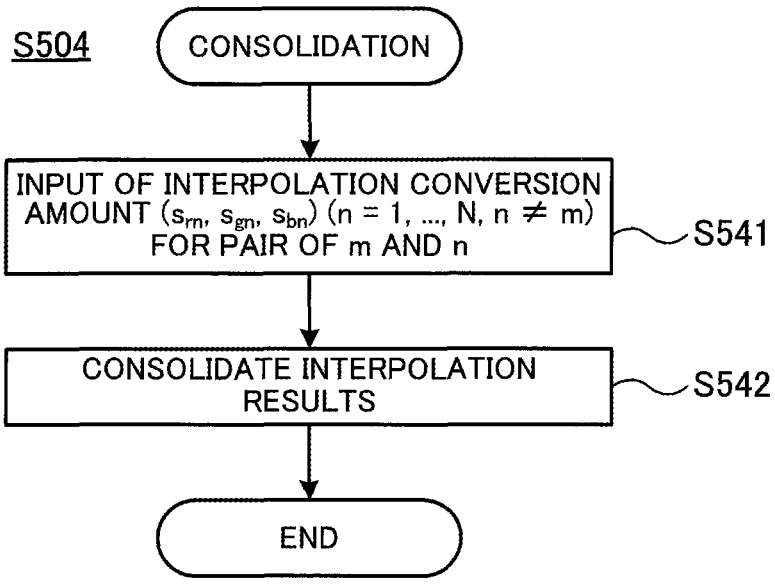

S504
CONSOLIDATION
INPUT OF INTERPOLATION CONVERSION AMOUNT (s_{rn}, s_{gn}, s_{bn}) (n = 1, ..., N, n ≠ m) FOR PAIR OF m AND n
S541
CONSOLIDATE INTERPOLATION RESULTS
S542
END

FIG. 30

INFORMATION PROCESSING APPARATUS AND COMPUTER-READABLE STORAGE MEDIUM STORING PROGRAM FOR INTERPOLATING AN INPUT COLOR

CROSS-REFERENCE TO RELATED APPLICATION

This application is based upon and claims the benefit of priority of the prior Japanese Patent Application No. 2014-020948, filed on Feb. 6, 2014, the entire contents of which are incorporated herein by reference.

FIELD

The embodiments discussed herein are related to an information processing apparatus and a computer-readable storage medium storing program.

BACKGROUND

When the colors of a captured image are different from the original colors, processing is performed that converts the color of each pixel of the image into the original color. This processing is called color correction. As a method for implementing color correction, there is, for example, a method which captures an image of an imaging object together with a sample containing a known color (hereinafter "reference color"), and converts the color of each pixel into the original color based on a change in the reference color.

However, the pixels of an image may represent a huge number of colors. Therefore, it is difficult to set all the colors that may be represented by the pixels as reference colors, and to provide conversion to the original color for each of the reference colors in advance. Accordingly, in the case of applying the method described above, interpolation processing is performed so as to obtain the color (hereinafter "input color") of each pixel from a preset reference color. Thus, conversion for the input color is obtained from conversion for the reference color. Then, color correction is performed based on the obtained conversion for the input color.

For example, there is a method that obtains conversion for an input color using volume interpolation. This method sets solids whose vertices are defined by reference colors in a color space, and obtains conversion of an input color using conversion of the reference colors on the vertices of the solid containing the input color. According to this method, the accuracy of color correction increases as the distance between the input color and each reference color used for interpolation processing decreases. In view of the above, as a method for improving the accuracy of color correction, there has been proposed a method that captures an image of a large number of reference colors so as to set a large number of solids in the color space.

There has also been proposed a method that arranges reference colors in a matrix form in a three-dimensional color space, and performs color correction using the reference colors. According to this method, the reference points located on the vertices of each of cubes of the matrix are used for interpolation processing. There has also been proposed a method that specifies a tetrahedron containing an input color, prints a chart for a detailed measurement of the inside of the specified tetrahedron, and corrects the input color based on the results of the color measurement of the printed chart. There has also been proposed a method that determines conversion of an input color based on a reference point located near the input color, without using volume interpolation. There has also been proposed a method that detects the position of a reference color from a captured image containing the reference color, and extracts the color of the reference color from the image.

Examples of the related art are disclosed in:

Japanese Laid-open Patent Publication No. 2000-048179;
Japanese Laid-open Patent Publication No. 02-023776;
Japanese Laid-open Patent Publication No. 2010-045560;
Japanese Laid-open Patent Publication No. 2003-125224; and
International Publication Pamphlet No. WO2013/145295.

In the case of the method that arranges reference colors in a matrix form in a color space, it is possible to uniquely identify a cube containing an input color from the coordinates of the input color in the color space. On the other hand, in the case where reference colors are not arranged in a matrix form, there is freedom in choosing a solid whose vertices are defined by reference colors. In this case, solids to be used for interpolation processing are set in advance, and color correction is performed using the reference colors on the vertices of the solid containing the input color.

The accuracy of color correction depends on the choice of a solid. Further, selecting appropriate vertices (reference colors) for a solid containing the input color imposes a heavy processing load. For example, consider a tetrahedron containing an input color. In this case, if there are N reference colors, then the number of combination of reference colors is of the order of N^4. Finding an appropriate combination for interpolation processing from such a large number of combinations imposes a heavy processing load. Accordingly, it takes a long time to perform interpolation processing for all the input colors contained in an image.

SUMMARY

According to one embodiment of the present invention, there is provided an information processing apparatus including: a memory configured to store a table including information on regions respectively occupied by a plurality of solids whose vertices are defined by a plurality of reference colors that are set in a color space, each of the solids having an evaluation value less than a setting value, the evaluation value decreasing as a length of edges thereof decreases, the solids being arranged such that faces thereof do not cross each other; and a processor configured to perform a procedure including: specifying a solid containing an input color with use of the table, and performing interpolation processing of the input color with use of the reference colors corresponding to the vertices of the specified solid.

The object and advantages of the invention will be realized and attained by means of the elements and combinations particularly pointed out in the claims.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory and are not restrictive of the invention.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** illustrates an example of an information processing apparatus according to a first embodiment;

FIG. **2** illustrates an example of the hardware of an image processing apparatus according to a second embodiment;

FIG. **3** is a block diagram illustrating an example of functions of the image processing apparatus according to the second embodiment;

FIG. **4** is a block diagram illustrating an example of functions of a table creation unit according to the second embodiment;

FIG. **5** illustrates an example of the settings of reference colors according to the second embodiment;

FIG. **6** illustrates an example of a solid number list according to the second embodiment;

FIG. **7** illustrates an example of a coordinate list according to the second embodiment;

FIG. **8** illustrates an example of a vertex list according to the second embodiment;

FIG. **9** illustrates a solid removal process according to the second embodiment;

FIG. **10** illustrates a map creation process according to the second embodiment;

FIG. **11** is a flowchart illustrating the flow of a table creation process according to the second embodiment;

FIG. **12** is a flowchart illustrating the flow of a candidate solid calculation process according to the second embodiment;

FIG. **13** is a flowchart illustrating the flow of an evaluation process and a solid selection process according to the second embodiment;

FIG. **14** is a flowchart illustrating the flow of a solid removal process according to the second embodiment;

FIG. **15** is a block diagram illustrating an example of functions of an image correction unit according to the second embodiment;

FIG. **16** illustrates a candidate solid search process according to the second embodiment;

FIG. **17** is a first diagram illustrating a conversion process according to the second embodiment;

FIG. **18** is a second diagram illustrating the conversion process according to the second embodiment;

FIG. **19** is a flowchart illustrating the flow of an image correction process according to the second embodiment;

FIG. **20** is a flowchart illustrating the flow of a solid determination process according to the second embodiment;

FIG. **21** illustrates a modified example (modification #1) of the second embodiment;

FIG. **22** is a flowchart illustrating the flow of a solid determination process according to the modified example (modification #1) of the second embodiment;

FIG. **23** is a flowchart illustrating the flow of an evaluation process and a solid selection process according to another modified example (modification #2) of the second embodiment;

FIG. **24** is a flowchart illustrating the flow of a solid determination process according to the other modified example (modification #2) of the second embodiment;

FIG. **25** illustrates an example of a non-map-using system applicable to the modified examples (modifications #1 and #2) of the second embodiment;

FIG. **26** is a first diagram illustrating the flow of a process according to the non-map-using system applicable to the modified examples (modifications #1 and #2) of the second embodiment;

FIG. **27** is a second diagram illustrating the flow of the process according to the non-map-using system applicable to the modified examples (modifications #1 and #2) of the second embodiment;

FIG. **28** is a third diagram illustrating the flow of the process according to the non-map-using system applicable to the modified examples (modifications #1 and #2) of the second embodiment;

FIG. **29** is a fourth diagram illustrating the flow of the process according to the non-map-using system applicable to the modified examples (modifications #1 and #2) of the second embodiment; and

FIG. **30** is a fifth diagram illustrating the flow of the process according to the non-map-using system applicable to the modified examples (modifications #1 and #2) of the second embodiment.

DESCRIPTION OF EMBODIMENTS

Hereinafter, embodiments will be described with reference to the accompanying drawings. Like reference numerals refer to like elements throughout, and a description of like elements will not be repeated.

(1) First Embodiment

A first embodiment will be described with reference to FIG. **1**. FIG. **1** illustrates an example of an information processing apparatus according to the first embodiment. An information processing apparatus **10** illustrated in FIG. **1** is an example of an information processing apparatus according to the first embodiment.

As illustrated in FIG. **1**, the information processing apparatus **10** includes a storage unit **11** and a computing unit **12**.

The storage unit **11** is a volatile storage device such as a random access memory (RAM) and the like, or may be a non-volatile storage device such as an HDD, a flash memory, and the like. The computing unit **12** is a processor such as a central processing unit (CPU), a digital signal processor (DSP), and the like. Alternatively, the computing unit **12** may be an electronic circuit such as an application specific integrated circuit (ASIC), a field programmable gate array (FPGA), and the like. The computing unit **12** executes programs stored in the storage unit **11** or other memories, for example.

The storage unit **11** stores a table TBL. The table TBL includes information on regions respectively occupied by a plurality of solids S_1, and S_2. The solid S_1 contains, on its vertices, reference colors P_1, P_2, and P_3 that are set in a color space. The solid S_2 contains, on its vertices, reference colors P_1, P_3, and P_4 that are set in the color space. Each of the solids S_1 and S_2 has an evaluation value greater than a setting value. Note that the shorter the edges thereof are, the greater the evaluation value is. The solids S_1 and S_2 are arranged so as not to overlap each other.

In the example of FIG. **1**, four reference colors P_1, P_2, P_3, and P_4 are set in the color space. Note that the description here is based on a three-dimensional color space defined by an R (red) axis, a G (green) axis, and a B (blue) axis. However, for illustration purposes, the B axis and one vertex of each of the solids S_1, and S_2 are omitted in FIG. **1**.

In two tables included in the table TBL, the value in an "R" field represents the coordinate value on the R axis (hereinafter "R coordinate value"), and the value in a "G" field represents the coordinate value on the G axis (hereinafter "G coordinate value"). That is, the table TBL illustrated in FIG. **1** includes a map that associates an R coordinate value with a solid number identifying a solid (the solid number of the solid S_1 is 1, and the solid number of the solid S_2 is 2), and a map that associates a G coordinate value with a solid number identifying a solid. These two maps are an example of region information. The number of maps included in the table TBL is less than the number of dimensions of the color space, for example.

The evaluation value mentioned above may be, for example, the total length of all the edges of a solid, the

average length of the edges, or the like. Alternatively, the evaluation value may be the length of each edge of a solid. In this case, the table TBL may include information on a solid if the evaluation values of the edges of the solid are greater than a setting value. Further, the setting value mentioned above may be, for example, a value set by the user in advance, a value determined from an evaluation based on experiments so as to achieve color correction of a desired level of accuracy, or the like.

The computing unit **12** specifies the solid S_1 containing an input color P_{IN} by referring to the table TBL. Further, the computing unit **12** performs interpolation processing of the input color P_{IN}, using the reference colors P_1, P_2, and P_3 corresponding to the vertices of the specified solid S_1.

For example, consider the case where the coordinates of P_1 are (50, 50, . . .); the coordinates of P_2 are (150, 50, . . .); the coordinates of P_3 are (100, 100, . . .); the coordinates of P_4 are (50, 200, . . .); and the coordinates of P_{IN} are (110, 60, . . .). Note that since the B axis is omitted in FIG. **1**, the coordinate value on the B axis is indicated by " . . . ".

In this case, the computing unit **12** refers to the table TBL, and extracts a set of solid numbers {1} corresponding to the R coordinate value (110) of the P_{IN}, and a set of solid numbers {1, 2} corresponding to the G coordinate value (60) of the P_{IN}. Further, the computing unit **12** calculates a product set of the extracted sets of solid numbers ({1}^{1, 2}={1}). Further, the computing unit **12** obtains, as a solid containing the input color P_{IN}, a solid (S_1 in this example) indicated by the calculated product set. Then, the computing unit **12** performs interpolation processing, using the reference colors P_1, P_2, and P_3 corresponding to the vertices of the solid S_1.

As described above, by using a solid that is set in accordance with an evaluation value based on the length of its edges, it is possible to perform high-accuracy color correction based on interpolation processing. Further, since information on solids appropriate for interpolation processing is stored as the table TBL, it is possible to easily specify a solid containing the input color, and thus to perform interpolation processing at high speed.

The above is a description of the first embodiment.

(2) Second Embodiment

Next, a second embodiment will be described. The second embodiment relates to a method that generates a map for determining a combination of reference points (solid) to be used for color correction, and performs color correction of an input color at high speed using the map. Hereinafter, a description will be given of the hardware, functions, and operations of an image processing apparatus capable of implementing this method.

(2-1) Hardware

The hardware of an image processing apparatus **100** will be described with reference to FIG. **2**. The image processing apparatus **100** illustrated in FIG. **2** is an example of an image forming apparatus according to the second embodiment. Note that FIG. **2** illustrates an example of the hardware of an image processing apparatus according to the second embodiment;

As illustrated in FIG. **2**, the image processing apparatus **100** includes a CPU **101** and a memory **102**. The CPU **101** may be a processor such as a DSP and the like, or may be an electronic circuit such as an ASIC, an FPGA, and the like. The memory **102** is a volatile storage device such as a RAM and the like, or a non-volatile storage device such as an HDD, a flash memory, and the like. The CPU **101** executes programs stored in the memory **102** or a storage medium **51** (described below), for example.

The storage medium **51**, an imaging apparatus **52**, and a color chart detection apparatus **53** are connected to the image processing apparatus **100**, for example. The storage medium **51** may be, for example, a portable storage medium such as a magnetic storage device, an optical storage medium, a magneto-optical storage medium, a semiconductor memory, and the like. Programs and data stored in the storage medium **51** are read by the CPU **101**.

The imaging apparatus **52** may be, for example, a digital camera or an information terminal having a camera function. An image captured by the imaging apparatus **52** (hereinafter "input image") is input to the image processing apparatus **100**, and is stored in the memory **102** via the CPU **101**. In this example, for purposes of explanation, an input image from the imaging apparatus **52** is stored in the memory **102**. However, for example, a modification is possible in which the CPU **101** reads an input image from an external storage apparatus, and stores the input image in the memory **102**.

The color chart detection apparatus **53** is an apparatus that extracts the positions of reference colors from an input image including a color chart in which the reference colors are disposed, and detects information on the reference colors from the input image. The functions of the color chart detection apparatus **53** may be implemented by, for example, an information processing apparatus such as a personal computer and an information terminal. The information on the reference colors extracted from the input image is stored in the memory **102** via the CPU **101**. In the case where the position of a color chart disposed in an input image is fixed in advance, the color chart detection apparatus **53** may be omitted.

The functions of the image processing apparatus **100** may be implemented by one or more computers. For example, the functions of the image processing apparatus **100** may be implemented by a system in which computers such as personal computers and server apparatuses and computers such as mobile phones and smart phones are combined. Further, at least one of the imaging apparatus **52** and the color chart detection apparatus **53** may be integrated with the image processing apparatus **100**. The following discussion is based on the image processing apparatus **100** illustrated in FIG. **2**.

The above is a description of the hardware of the image processing apparatus **100**.

(2-2) Functions of Image Processing Apparatus

The following describes the functions of the image processing apparatus **100** with reference to FIG. **3**. FIG. **3** is a block diagram illustrating an example of functions of the image processing apparatus **100** according to the second embodiment.

As illustrated in FIG. **3**, the image processing apparatus **100** includes a table creation unit **111** and an image correction unit **112**. The functions of the table creation unit **111** and the image correction unit **112** are implemented by the CPU **101** and the memory **102** described above.

The table creation unit **111** creates a table including a plurality of maps used for interpolation processing of input colors from a set of reference colors that are set in the color space. The table includes information indicating a combination of reference colors appropriate for interpolation processing for an arbitrary input color. A combination of reference colors in the color space is represented by a solid whose vertices are defined by reference colors. In the following description, for purposes of explanation, a triangular pyramid

(a type of convex hull) whose vertices are defined by four reference colors is assumed as the shape of the solid.

The image correction unit **112** specifies a triangular pyramid containing the input color by referring to the maps that are included in the table created by the table creation unit **111**, and performs color correction of the input color based on the four reference colors corresponding to the vertices of the specified triangular pyramid. In this step, the image correction unit **112** performs interpolation processing so as to replace information on conversion for the reference colors with information on conversion for the input color, and convert the input color into the original color based on the information on conversion for the input color. The information on conversion for the reference colors is information that gives a conversion equation between each reference color extracted from an image of a color chart and a color that is set in advance with respect to the reference color.

The table creation unit **111** and the image correction unit **112** will be further described below.

(2-2-1) Table Creation Unit

First, the table creation unit **111** will be described.

(Functional Blocks)

The functions of the table creation unit **111** will be further described with reference to FIG. **4**. In the following description, FIGS. **5** through **10** will be referred to as needed.

FIG. **4** is a block diagram illustrating an example of functions of the table creation unit **111** according to the second embodiment. FIG. **5** illustrates an example of the settings of reference colors according to the second embodiment. FIG. **6** illustrates an example of a solid number list according to the second embodiment.

FIG. **7** illustrates an example of a coordinate list according to the second embodiment. FIG. **8** illustrates an example of a vertex list according to the second embodiment. FIG. **9** illustrates a solid removal process according to the second embodiment. FIG. **10** illustrates a map creation process according to the second embodiment.

As illustrated in FIG. **4**, the table creation unit **111** includes a candidate solid calculation unit **131**, an evaluation unit **132**, a solid selection unit **133**, a solid removal unit **134**, and a map creation unit **135**.

The candidate solid calculation unit **131** extracts, for each of all the sets of coordinates contained in the color space, solids containing the set of coordinates, and specifies the extracted solids as candidate solids. The color space is set such that, for example, the R coordinate value is in a range from 0 to 255; the G coordinate value is in a range from 0 to 255, and the B coordinate value is in a range from 0 to 255. The evaluation unit **132** gives, for each of the candidate solids specified by the candidate solid calculation unit **131**, an evaluation value based on the edges of the candidate solid.

The solid selection unit **133** selects solids to be stored in a map, based on the evaluation values given to the candidate solids by the evaluation unit **132**. The solid removal unit **134** removes candidate solids overlapping the solids selected by the solid selection unit **133**. The solid selection unit **133** and the solid removal unit **134** repeat selection of solids and removal of solids while retaining (not removing) the already selected solids, until the color space is filled with the solids selected by the solid selection unit **133**. After the color space is filled up, the map creation unit **135** creates a look-up table (map) that associates each set of coordinates of the color space and the solid containing the set of coordinates and selected by the solid selection unit **133**.

The functions of the table creation unit **111** will now be further described with reference to an example of a color space and reference colors illustrated in FIG. **5**.

Note that the following description is based on a three-dimensional color space defined by an R axis, a G axis, and a B axis. However, for illustration purposes, the B (blue) axis is omitted in the color space illustrated in FIG. **5**. Further, the solid in the color space is represented by a triangle whose vertices are defined by three reference colors. Due to these constraints on representation, the B coordinate value may be omitted and indicated by " . . . " in the following description. Further, N reference colors are disposed in the color space.

In the example of FIG. **5**, seven reference colors $P_1, \ldots,$ and P_7 are illustrated. Further, a solid whose vertices are defined by P_1, P_2, and P_4, a solid whose vertices are defined by P_1, P_4, and P_7, and a solid whose vertices are defined by P_1, P_3, and P_6 are illustrated. In this way, various solids may be formed depending on the combination of reference colors. Accordingly, when an input color is given, a plurality solids containing the input color may be obtained. The candidate solid calculation unit **131** assumes that all sets of coordinates included in the color space as input colors, and extracts solids containing the respective input colors.

Each of N reference colors is represented by $\{(r_n, g_n, b_n), n=1, \ldots, N\}$, where r_n is the R coordinate value of an n-th reference color P_n; g_n is the G coordinate value of the n-th reference color P_n; and b_n is the B coordinate value of the n-th reference color P_n. Further, the input color is represented by (r_m, g_m, b_m). If a three-dimensional color space is assumed, the smallest solid containing an input color is a triangular pyramid having for vertices. Accordingly, in the following description, it is assumed that the shape of the solid is a triangular pyramid.

(Candidate Solid Calculation Unit **131**)

When determining whether an input color is contained in a solid, the candidate solid calculation unit **131** calculates a center of gravity (r_g, g_g, b_g) of the four reference colors defining the vertices of the solid. If the input color is contained in the solid, both the center of gravity of the solid and the input color are in the same one of two half-spaces separated by a face of the solid. Based on these characteristics, the candidate solid calculation unit **131** determines whether the direction from the center of the gravity of the solid toward each of the faces of the solid matches the direction from the input color toward each of the faces of the solid, and determines whether the input color is contained in the solid based on the determination result. If these two direction match, the candidate solid calculation unit **131** determines that the input color is contained in the solid.

For example, consider an equation of a plane represented by expression (1) below. Four coefficients $k_1, \ldots,$ and k_4 are given by expressions (2) through (5) below. Here, (r_{n1}, g_{n1}, b_{n1}), (r_{n2}, g_{n2}, b_{n2}), and (r_{n3}, g_{n3}, b_{n3}) are three vertices defining the plane.

There are four combinations of three out of four vertices of a triangular pyramid. The candidate solid calculation unit **131** determines, for each of these four combinations, whether the value of J obtained by assigning (r_g, g_g, b_g) to (r, g, b) and the value of J obtained by assigning (r_m, g_m, b_m) to (r, g, b) have the same sign.

If the J-values have the same sign in each of the combinations, the candidate solid calculation unit **131** determines that the input color (r_m, g_m, b_m) is contained in the solid. On the other hand, if the J-values have different signs in at least one of the combinations, the candidate solid calculation unit **131** determines that the input color (r_m, g_m, b_m) is not contained in the solid. The candidate solid calculation unit **131** performs this determination process for all the combinations of the reference colors.

$$J=k_1\cdot r+k_2\cdot g+k_3\cdot b+k_4 \quad (1)$$

$$k_1=(g_{n2}-g_{n1})\cdot(b_{n3}-b_{n1})-(g_{n3}-g_{n1})\cdot(b_{n2}-b_{n1}) \quad (2)$$

$$k_2=(b_{n2}-b_{n1})\cdot(r_{n3}-r_{n1})-(b_{n3}-b_{n1})\cdot(r_{n2}-r_{n1}) \quad (3)$$

$$k_3=(r_{n2}-r_{n1})\cdot(g_{n3}-g_{n1})-(r_{n3}-r_{n1})\cdot(g_{n2}-g_{n1}) \quad (4)$$

$$k_4=-(k_1\cdot r_{n1}+k_2\cdot g_{n1}+k_3\cdot b_{n1}) \quad (5)$$

In the example of FIG. **5**, the candidate solid calculation unit **131** may create a solid number list illustrated in FIG. **6** as the results of the determination processes described above. The solid number list is a table in which a set of coordinates in the color space is associated with a solid number of a solid containing the set of coordinates.

The candidate solid calculation unit **131** stores a set of coordinates of an input color contained in a solid and a solid number of the solid containing the input color in association with each other in the solid number list. If there are a plurality of solids that contain the same input color, a plurality of solid numbers are associated with the same set of coordinates as illustrated in FIG. **6**.

Further, the candidate solid calculation unit **131** creates a coordinate list (see FIG. **7**) that associates each vertex of each of the solids of the solid numbers stored in the solid number list with a set of coordinates of the vertex. The coordinate list is a table in which a vertex number identifying a reference color is associated with the coordinate values of the reference color in the color space.

Further, the candidate solid calculation unit **131** creates a vertex list (see FIG. **8**) that associates each solid number stored in the solid number list with vertices of the solid having the solid number. The vertex list is a table in which a solid number identifying a solid is associated with four vertex numbers identifying the vertices of the solid. The solid number list, the coordinate list, and the vertex list are stored in the memory **102**. By referring to these lists, it is possible to easily identify the coordinates of vertices of a solid and a solid containing given coordinates.

(Evaluation Unit **132**)

In the following description, the solid number is represented by s, and the vertex numbers indicating four vertices of the solid with the solid number s are represented by $\{n_{s1}, n_{s2}, n_{s3}, n_{s4}\}$. The evaluation unit **132** calculates an evaluation value for each of the solids having the solid numbers stored in the solid number list. The smaller the solid is, the better (smaller) the evaluation value becomes. Note that a small solid is a solid having short edges. That is, among solids having the same volume, solids having shorter edges have smaller evaluation values. An evaluation value J_s of the solid with the solid number s is given by, for example, expression (6) below.

Alternatively, the evaluation value J_s may be obtained by expression (7) below. The evaluation value J_s represented by expression (7) below is the sum of evaluation values J_s represented by the expression (6) below with respect to all the coordinates of the color space. With this method, the evaluation unit **132** calculates an evaluation value J_s for each of the solids of the solid numbers stored in the solid number list.

$$J_s=\sum_{\substack{i,j=1\\ i\neq j}}^{4}\{(r_{nsi}-r_{nsj})^2+(g_{nsi}-g_{nsj})^2+(b_{nsi}-b_{nsj})^2\} \quad (6)$$

-continued

$$J_s=\sum_{\substack{r,g,b=0\\ (r,g,b)\in s}}^{255}\ \sum_{\substack{i,j=1\\ i\neq j}}^{4}\{(r_{nsi}-r_{nsj})^2+(g_{nsi}-g_{nsj})^2+(b_{nsi}-b_{nsj})^2\} \quad (7)$$

(Solid Selection Unit **133** and Solid Removal Unit **134**)

The evaluation value J_s calculated by the evaluation unit **132** is input to the solid selection unit **133**. The solid selection unit **133** extracts a solid having the smallest evaluation value J_s for each of the coordinates stored in the solid number list. The solid selection unit **133** stores a solid number s_{min} of the extracted solid in a selected-solid number list. The selected-solid number list is a list storing the solid number s_{min} of the solid extracted by the evaluation unit **132**. The selected-solid number list is stored in the memory **102**.

For example, in the case of the solid number list of FIG. **6**, two solid numbers **1** and **2** are associated with the coordinates (60, 50, . . .). In this case, the evaluation unit **132** compares an evaluation value J_1 of the solid with the solid number **1** and an evaluation value J_2 of the solid with the solid number **2**, and stores the solid number of the solid having a smaller value in the selected-solid number list. For example, if the evaluation value J_1 is less than the evaluation value J_2 (if $s_{min}=1$), the solid selection unit **133** stores the solid number **1** in the selected-solid number list.

When the solid number s_{min} is stored in the selected-solid number list, the solid removal unit **134** removes a solid number of a solid overlapping the solid with the solid number s_{min} from the solid number list. Further, the solid removal unit **134** sores the solid number removed from the solid number list in a solid removal list. For example, if $s_{min}=1$, the solid removal unit **134** removes a solid number **3** of a solid (an overlapping solid) containing the same coordinates as the solid with the solid number **1** from the solid number list, as illustrated in FIG. **9**. Further, the solid removal unit **134** removes the solid number s_{min} from the solid number list, as illustrated in FIG. **9**.

(Map Creation Unit **135**)

The processing by the solid selection unit **133** and the solid removal unit **134** is repeated, so that an appropriate set of solids for filling the color space are selected. The map creation unit **135** creates a map (look-up table) for identifying a combination of reference colors to be used for interpolation of an arbitrary input color, based on the solid numbers stored in the selected-solid number list.

The map is created for each coordinate axis of the color space. For example, the map creation unit **135** creates a map MP_R associating each R coordinate value with a solid number, a map MP_G associating each G coordinate value with a solid number, and a map MP_B associating each B coordinate value with a solid number.

For example, consider the case of creating the map MP_R. In this case, the map creation unit **135** refers to the solid number list, and extracts a solid number corresponding to each R coordinate value.

For example, if solid numbers **1** and **2** correspond to an R coordinate value 50 (R=50), the map creation unit **135** adds the R coordinate value (50) and the solid numbers **1** and **2** in association with each other to the map MP_R, as illustrated in FIG. **10**. At this point, the map creation unit **135** does not consider the G coordinate value and the B coordinate value corresponding to the solid numbers **1** and **2**. The same applies to other R coordinate values. Further, the map creation unit **135** creates the maps MP_G and MP_B in the same way. The

table TBL including the maps MP_R, MP_G, and MP_B is input to the image correction unit **112**.

In the above-described creation process, the map creation unit **135** extracts, for each of the solids of the solid numbers stored in the solid number list, the maximum value and the minimum value of each of the coordinate values in the region occupied by the solid, and associates each of coordinate values in a rage between the extracted maximum and minimum values with a solid number, for example. Each of these maximum and minimum values is any one of the coordinate values of the vertices of the solid. Accordingly, by comparing the coordinate values of the four vertices of a solid, it is possible to easily obtain the maximum and minimum values of the R coordinate value, the maximum and minimum values of the G coordinate value, and the maximum and minimum values of the B coordinate value.

The above is the functions of the table creation unit **111**.

(General Flow of Process)

The following describes the flow of the process performed by the table creation unit **111** with reference to FIG. **11**. FIG. **11** is a flowchart illustrating the flow of a table creation process according to the second embodiment.

As illustrated in FIG. **11**, the table creation unit **111** causes the candidate solid calculation unit **131** to extract solids containing each set of coordinates of the color space as candidate solids, and store information associating solid numbers of the extracted candidate solids with coordinates in the solid number list (S**101**).

Then, the table creation unit **111** causes the evaluation unit **132** to calculate an evaluation value J_s represented by the above expression (6) or (7) for the solid with the solid number s on the solid number list (S**102**).

Then, the table creation unit **111** causes the solid selection unit **133** to select a candidate solid having the smallest evaluation value J_s among the candidate solids containing the same coordinates, and store a solid number of the selected candidate solid in the selected-solid number list (S**103**).

Then, the table creation unit **111** causes the solid removal unit **134** to extract a solid overlapping the solid with the solid number stored in the selected-solid number list, and remove a solid number of the extracted solid from the solid number list (S**104**). Further, the table creation unit **111** causes the solid removal unit **134** to store the solid number removed from the solid number list in the solid removal list. Further, the table creation unit **111** causes the solid removal unit **134** to remove the solid number stored in the selected-solid number list from the solid number list.

Then, the table creation unit **111** determines whether there is a remaining candidate solid after the operation of step S**104** (S**105**). If there is a remaining candidate solid, the process returns to step S**103**. On the other hand, if there is no remaining candidate solid, the process proceeds to step S**106**. When the process proceeds to step S**106**, the table creation unit **111** causes the map creation unit **135** to create a map based on the selected-solid number list (S**106**). The map created in step S**106** is input to the image correction unit **112**. Further, when the operation of step S**106** completes, a series of operations illustrated in FIG. **11** ends.

The above is a description of the general flow of the process performed by the table creation unit **111**.

(Candidate Solid Calculation)

The process of step S**101** will now be further described with reference to FIG. **12**. FIG. **12** is a flowchart illustrating the flow of a candidate solid calculation process according to the second embodiment. The process illustrated in FIG. **12** is performed by the candidate solid calculation unit **131**.

As illustrated in FIG. **12**, the candidate solid calculation unit **131** sets solid numbers based on combinations of reference colors (S**111**). For example, the candidate solid calculation unit **131** sequentially selects a combination of four reference colors, and sequentially assigns a solid whose vertices are defined by the selected reference colors with a solid number. Further, in the operation of step S**111**, the candidate solid calculation unit **131** generates a vertex list that associates the solid number with the vertices, using vertex numbers identifying the reference colors on the vertices.

Then, the candidate solid calculation unit **131** sets a parameter (input color parameter (r, g, b)) for identifying the input color to (0, 0, 0) (S**112**). Then, the candidate solid calculation unit **131** sets a parameter for specifying a solid number (solid number parameter s) to 0. Then, the candidate solid calculation unit **131** extracts the vertices of the solid with the solid number s from the vertex list (S**114**).

Then, the candidate solid calculation unit **131** determines whether the solid with the solid number s contains the input color (r, g, b) (S**115**). If the solid with the solid number s contains the input color (r, g, b), the process proceeds to step S**116**. On the other hand, if the solid with the solid number s does not contain the input color (r, g, b), the process proceeds to step S**117**. When the process proceeds to step S**116**, the candidate solid calculation unit **131** adds a pair of the solid number s and the input color (r, g, b) to the solid number list (S**116**). When the operation of step S**116** completes, the process proceeds to step S**117**.

When the process proceeds to step S**117**, the candidate solid calculation unit **131** determines whether s is the maximum value of the solid number (S**117**). If s is the maximum value of the solid number, the process proceeds to step S**119**. On the other hand, if s is not the maximum value of the solid number, the process proceeds to step S**118**. When the process proceeds to step S**118**, the candidate solid calculation unit **131** performs update processing that increments s by 1 (S**118**). When the operation of step S**118** completes, the process returns to step S**114**.

When the process proceeds to step S**119**, the candidate solid calculation unit **131** determines whether (r, g, b) is the last input color (S**119**). If (r, g, b) is the last input color, a series of operations illustrated in FIG. **12** ends. On the other hand, if (r, g, b) is not the last input color, the process proceeds to step S**120**.

When the process proceeds to step S**120**, the candidate solid calculation unit **131** performs update processing that changes (r, g, b) to the next coordinates (S**120**). For example, if the direction of scanning the color space is determined in advance, the values of (r, g, b) are changed so as to specify the adjacent coordinates in the scanning direction. When the operation of step S**120** completes, the process returns to step S**113**.

The above is a description of the process of step S**101**.

(Evaluation and Solid Selection)

The processes of steps S**102** and S**103** will now be further described with reference to FIG. **13**. FIG. **13** is a flowchart illustrating the flow of an evaluation process and a solid selection process according to the second embodiment. The processes illustrated in FIG. **13** are performed by the evaluation unit **132** and the solid selection unit **133**.

As illustrated in FIG. **13**, the evaluation unit **132** sets a minimum solid number parameter s_{min} for identifying a solid number having the smallest evaluation value to 0 (S**131**). Then, the evaluation unit **132** sets a minimum evaluation value parameter J_{min} used for calculating the smallest evaluation value to 0 (S**132**). Then, the evaluation unit **132** sets a

solid number parameter s for specifying a solid number to 0 (S133). It is to be noted that steps S131, S132, and S133 may be performed in any order.

Then, the evaluation unit **132** calculates an evaluation value J_s of the solid with the solid number s (S134). For example, the evaluation unit **132** calculates the evaluation value J_s based on the above expression (6) or (7). Then, the solid selection unit **133** determines whether the solid number s is on the solid number list (S135). If the solid number s is on the solid number list, the process proceeds to step S138. On the other hand, if the solid number s is not on the solid number list, the process proceeds to step S136.

When the process proceeds to step S136, the solid selection unit **133** compares the minimum evaluation value parameter J_{min} and the evaluation value J_s, and determines whether the minimum evaluation value parameter J_{min} is greater than the evaluation value J_s (S136). If the minimum evaluation value parameter J_{min} is greater than the evaluation value J_s, the process proceeds to step S137. On the other hand, if the minimum evaluation value parameter J_{min} is not greater than the evaluation value J_s, the process proceeds to step S138.

When the process proceeds to step S137, the solid selection unit **133** sets the minimum evaluation value parameter J_{min} to J_s, and sets the minimum solid number parameter s_{min} to s (step S137). When the operation of step S137 completes, the process proceeds to step S138. When the process proceeds to step S138, the solid selection unit **133** determines whether s is the maximum value of the solid number (S138). When s is the maximum value of the solid number, the process proceeds to step S140. On the other hand, if s is not the maximum value of the solid number, the process proceeds to step S139.

When the process proceeds to step S139, the solid selection unit **133** performs update processing that increments s by 1 (S139). When the processing of step S139 completes, the process returns to step S134. When the process proceeds to step S140, the solid selection unit **133** adds the solid number s_{min} to the selected-solid number list (S140). When the operation of step S140 completes, a series of operations illustrated in FIG. **13** ends.

The above is a description of the processes of step S102 and S103.

(Solid Removal)

The process of step S104 will now be further described with reference to FIG. **14**. FIG. **14** is a flowchart illustrating the flow of a solid removal process according to the second embodiment. The process illustrated in FIG. **14** is performed by the solid removal unit **134**.

As illustrated in FIG. **14**, the solid removal unit **134** receives an input of the minimum solid number s_{min} (S151). In this step, the minimum solid number s_{min} stored in the selected-solid number list is input. Then, the solid removal unit **134** sets an input color parameter (r, g, b) for specifying the input color to (0, 0, 0) (S152).

Then, the solid removal unit **134** determines whether there is s_{min} corresponding to (r, g, b) (S153). If there is s_{min} corresponding to (r, g, b), the process proceeds to step S154. On the other hand, if there is no s_{min} corresponding to (r, g, b), the process proceeds to step S155. When the process proceeds to step S154, the solid removal unit **134** adds a solid number of a solid which is not the solid with the solid number s_{min} and contains (r, g, b) to the solid removal list, and removes the solid number from the solid number list (S154). When the operation of step S154 completes, the process proceeds to step S155.

When the process proceeds to step S155, the solid removal unit **134** determines whether (r, g, b) is the last input color (S155). If (r, g, b) is the last input color, the process proceeds to step S157. On the other hand, if (r, g, b) is not the last input color, the process proceeds to step S156. When the process proceeds to step S156, the solid removal unit **134** performs update processing that changes (r, g, b) to the next coordinates (S156). When the operation of step S156 completes, the process returns to step S153.

When the process proceeds to step S157, the solid removal unit **134** adds the solid number s_{min} to the solid removal list, and removes the solid number s_{min} from the solid number list (S157). When the operation of step S157 completes, a series of operations illustrated in FIG. **14** ends.

The above is a description of the process of step S104.

The above is a description of the table creation unit **111**.

(2-2-2) Image Correction Unit

The following describes the image correction unit **112**.

(Functional Blocks)

The functions of the image correction unit **112** will be further described with reference to FIG. **15**. In the following description, FIGS. **16** through **18** will be referred to as needed.

FIG. **15** is a block diagram illustrating an example of functions of the image correction unit **112** according to the second embodiment. FIG. **16** illustrates a candidate solid search process according to the second embodiment. FIG. **17** is a first diagram illustrating a conversion process according to the second embodiment. FIG. **18** is a second diagram illustrating the conversion process according to the second embodiment.

As illustrated in FIG. **15**, the image correction unit **112** includes a candidate solid search unit **141**, a solid determination unit **142**, and a conversion unit **143**. The functions of the candidate solid search unit **141**, the solid determination unit **142**, and the conversion unit **143** are implemented by the CPU **101** and the memory **102** described above. The image correction unit **112** stores the table (look-up table) created by the table creation unit **111** and including a plurality of maps.

The candidate solid search unit **141** acquires color information on an input color of an arbitrary pixel included in an image, and calculates candidate reference colors to be used for interpolation of the input color by referring to the maps. The image may be one obtained from the imaging apparatus **52** or may be one stored in advance in the memory **102** or the storage medium **51**. In the case where there are a plurality of candidate combinations of reference colors, the solid determination unit **142** selects one of the plurality of candidate combinations. The conversion unit **143** performs color correction for the input color by performing interpolation processing based on the combination of reference colors selected by the solid determination unit **142**.

The functions of the image correction unit **112** will now be further described in connection with an example in which maps MP_R, MP_G, and MP_B of FIG. **16** are provided (the map MP_B is omitted in FIG. **16**). Further, color correction processing will be further described with reference to FIGS. **17** and **18**.

(Candidate Solid Search Unit **141** and Solid Determination Unit **142**)

The candidate solid search unit **141** refers to the maps MP_R, MP_G, and MP_B, and extracts a solid containing an input color as a candidate solid. In the example of FIG. **16**, an input color P_{IN}(110, 60, . . .) is given. In this case, the candidate solid search unit **141** extracts a solid number corresponding to the R coordinate value (110) of the input color P_{IN} from the map MP_R. In the example of FIG. **16**, a solid number {1} is extracted.

Similarly, the candidate solid search unit **141** extracts a solid number corresponding to the G coordinate value (60) of the input color P_{IN} from the map MP_G. In the example of FIG.

16, two solid numbers {1, 2} are extracted. Similarly, the candidate solid search unit **141** extracts a solid number corresponding to the B coordinate value of the input color P_{IN}.

The candidate solid search unit **141** generates a product set ({1}^{1, 2}^{ . . . }) of the solid number {1} corresponding to the R coordinate value (110), the solid numbers {1, 2} corresponding to the G coordinate value (60), and the solid number { . . . } corresponding to the B coordinate value. If the solid number { . . . } corresponding to the B coordinate value includes 1, the product set is {1}. Note that "^" represents a logical AND. In this way, the candidate solid search unit **141** extracts a candidate solid containing the input color P_{IN}, using the three maps MP_R, MP_G, and MP_B. Note that in the case where a plurality of candidate solids are extracted, the solid determination unit **142** extracts one of the candidate solids containing the input color P_{IN}.

The solid determination unit **142** selects a candidate solid containing the input color P_{IN} from the plurality of candidate solids. This selection process is implemented based on the above expressions (1) through (5). That is, similar to the candidate solid calculation unit **131** of the table creation unit **111**, the solid determination unit **142** calculates the coordinates of the center of gravity of the candidate solids, and compares the sing of the value of J obtained by assigning the input color P_{IN} to the above expression (1) and the sign of the value of J obtained by assigning the coordinates of the center of gravity to the above expression (1). Then, the solid determination unit **142** extracts a candidate solid whose two J-values have the same sign. The extracted candidate solid is input to the conversion unit **143** as a solid to be used for color correction of the input color P_{IN}.

(Conversion Unit **143**)

The conversion unit **143** performs color correction of the input color P_{IN}, using the reference colors located on the vertices of the solid input from the solid determination unit **142**. For example, as illustrated in FIG. **17**, the coordinates of the input color P_{IN} are represented by (r, g, b), and four reference colors P_0, P_1, P_2, and P_3 used for color correction are represented by (r_0, g_0, b_0), (r_1, g_1, b_1), (r_2, g_2, b_2), and (r_3, g_3, b_3). Note that in the example of FIG. **17**, P_3 is omitted.

Further, a vector V_1 from P_0 to P_1 is $(r_1-r_0, g_1-g_0, b_1-b_0)$. Further, a vector V_2 from P_0 to P_2 is $(r_2-r_0, g_2-g_0, b_2-b_0)$. Further, a vector V_3 from P_0 to P_3 is $(r_3-r_0, g_3-g_0, b_3-b_0)$. Note that conversion represented by vectors V_1, V_2, and V_3 is given in advance. Further, the input color $P_{IN}(r, g, b)$ is represented by expression (8-1) below, using coefficients h_1, h_2, and h_3.

$$\begin{bmatrix} r \\ g \\ b \end{bmatrix} = \begin{bmatrix} r_1 - r_0 & r_2 - r_0 & r_3 - r_0 \\ g_1 - g_0 & g_2 - g_0 & g_3 - g_0 \\ b_1 - b_0 & b_2 - b_0 & b_3 - b_0 \end{bmatrix} \begin{bmatrix} h_1 \\ h_2 \\ h_3 \end{bmatrix} + \begin{bmatrix} r_0 \\ g_0 \\ b_0 \end{bmatrix} \quad (8\text{-}1)$$

Since the three vectors V_1, V_2, and V_3 are obtained from the coordinates of the reference colors, when the coordinates of the input color P_{IN} are given, the coefficients h_1, h_2, and h_3 are obtained from expression (8-2) below which is obtained by modifying the above expression (8-1). Note that the superscript "−1" denotes the inverse matrix.

$$\begin{bmatrix} h_1 \\ h_2 \\ h_3 \end{bmatrix} = \begin{bmatrix} r_1 - r_0 & r_2 - r_0 & r_3 - r_0 \\ g_1 - g_0 & g_2 - g_0 & g_3 - g_0 \\ b_1 - b_0 & b_2 - b_0 & b_3 - b_0 \end{bmatrix}^{-1} \begin{bmatrix} r - r_0 \\ g - g_0 \\ b - b_0 \end{bmatrix} \quad (8\text{-}2)$$

The coordinates of the original colors corresponding to the reference colors P_0, . . . , and P_3 (the coordinates that are set in advance for the reference colors) are represented by (r_{0s}, g_{0s}, b_{0s}), (r_{1s}, g_{1s}, b_{1s}). (r_{2s}, g_{2s}, b_{2s}), and (r_{3s}, g_{3s}, b_{3s}). Using these representations, the coordinates (r_s, g_s, b_s) of the input color P_{IN} after color correction are given by expression (9) below. The conversion unit **143** calculates the coefficients h_1, h_2, and h_3 based on the above expression (8-2), and performs color correction for converting the input color P_{IN} to the original color based on expression (9) below, as illustrated in FIG. **18**.

$$\begin{bmatrix} r_s \\ g_s \\ b_s \end{bmatrix} = \begin{bmatrix} r_{1s} - r_{0s} & r_{2s} - r_{0s} & r_{3s} - r_{0s} \\ g_{1s} - g_{0s} & g_{2s} - g_{0s} & g_{3s} - g_{0s} \\ b_{1s} - b_{0s} & b_{2s} - b_{0s} & b_{3s} - b_{0s} \end{bmatrix} \begin{bmatrix} h_1 \\ h_2 \\ h_3 \end{bmatrix} + \begin{bmatrix} r_{0s} \\ g_{0s} \\ b_{0s} \end{bmatrix} \quad (9)$$

The above is a description of the image correction unit **112**.

(General Flow of Process)

The following describes the flow of the process performed by the image correction unit **112** with reference to FIG. **19**. FIG. **19** is a flowchart illustrating the flow of an image correction process according to the second embodiment.

As illustrated in FIG. **19**, the image correction unit **112** causes the candidate solid search unit **141** to refer to the maps MP_R, MP_G, and MP_B created by the table creation unit **111**, and extract solids containing the input color P_{IN} as candidate solids (S**201**). Then, the image correction unit **112** causes the solid determination unit **142** to select a solid containing the input color P_{IN} from the candidate solids extracted in step S**201** (S**202**).

Then, the image correction unit **112** causes the conversion unit **143** to perform color correction of the input color P_{IN}, using conversion of the reference colors located on the vertices of the solid selected in step S**202** (S**203**). When the operation of step S**203** completes, a series of operations illustrated in FIG. **19** ends.

(Solid Determination)

The process of step S**202** will now be further described with reference to FIG. **20**. FIG. **20** is a flowchart illustrating the flow of a solid determination process according to the second embodiment. The process illustrated in FIG. **20** is performed by the solid determination unit **142**.

As illustrated in FIG. **20**, the solid determination unit **142** receives an input of a solid count c representing the number of candidate solids (S**211**). Further, the solid determination unit **142** receives a solid number s_j (j=1, . . . , c) identifying each candidate solid (S**212**). Then, the solid determination unit **142** determines whether c is 1 (S**213**). If c is 1, the solid determination unit **142** selects the solid with the solid number s_1, and the process proceeds to step S**215**. On the other hand, if c is not 1, the process proceeds to step S**214**.

When the process proceeds to step S**214**, the solid determination unit **142** selects a solid containing the input color from solids with solid numbers s_j (j=1, . . . , c) (S**214**). When the operation of step S**214** completes, the process proceeds to step S**215**. When the process proceeds to step S**215**, the solid determination unit **142** determines the selected solid as a solid to be used for conversion of the input color (S**215**). When the operation of step S**215** completes, a series of operations illustrated in FIG. **20** ends.

The above is a description of the process of step S**202**.

The above is a description of the image correction unit **112**.

(2-3) Modification #1 (Combined Use a of Non-Map-Using System)

A modified example (modification #1) of the second embodiment will now be described with reference to FIGS. **21** and **22**. The modification #1 relates to a method to which a process is added that is performed in the case where an input

color is located outside the region filled with solids whose vertices are defined by reference colors. FIG. **21** illustrates the modified example (modification #1) of the second embodiment. FIG. **22** is a flowchart illustrating the flow of a solid determination process according to the modified example (modification #1) of the second embodiment.

The above description is based on the assumption that the input color is contained in any of solids whose vertices are defined by reference colors. That is, in the case where there is no solid containing the input color, color correction processing for the input color is optional. The modification #1 proposes a system (hereinafter "non-map-using system") that performs color correction of the input color P_{IN} without using the maps MP_R, MP_G, and MP_B in the case where there is no solid containing the input color (see FIG. **21**).

In the case of applying the modification #1, the above-described solid process is modified as illustrated in FIG. **22**. The conversion unit **143** selects a method for color correction (a system using maps or the non-map-using system) based on a system flag that is set in the process illustrated in FIG. **22**. The system flag is a flag that is referred to when selecting a method for color correction. The non-map-using system is selected when the system flag is 1, and the color correction method using maps is selected when the system flag is 0.

As illustrated in FIG. **22**, the solid determination unit **142** sets the system flag to 0 (S**301**). Further, the solid determination unit **142** receives an input of a solid count c representing the number of candidate solids (S**302**). Further, the solid determination unit **142** receives a solid number s_j (j=1, . . . , c) identifying each candidate solid (S**303**). Note that when c is 0, the solid number s_j (j=1, . . . , c) is not input.

Then, the solid determination unit **142** determines whether c is 0 (S**304**). If c is 0, the process proceeds to step S**309**. On the other hand, if c is not 0, the process proceeds to step S**305**. When the process proceeds to step S**305**, the solid determination unit **142** determines whether c is 1 (S**305**). If c is 1, the solid determination unit **142** selects the solid with the solid number s_1, and the process proceeds to step S**307**. On the other hand, if c is not 1, the process proceeds to step S**306**.

When the process proceeds to step S**306**, the solid determination unit **142** selects a solid containing the input color from solids with solid numbers s_j (j=1, . . . , c) (S**306**). When the operation of step S**306** completes, the process proceeds to step S**307**. When the process proceeds to step S**307**, the solid determination unit **142** determines the selected solid as a solid to be used for conversion of the input color (S**307**).

Then, the solid determination unit **142** determines whether the solid determined in step S**307** contains the input color (S**308**). If the solid determined in step S**307** contains the input color, a series of operations illustrated in FIG. **22** ends. On the other hand, if the solid determined in step S**307** does not contain the input color, the process proceeds to step S**309**. When the process proceeds to step S**309**, the solid determination unit **142** sets the system flag to 1 (S**309**). When the operation of step S**309** completes, a series of operations illustrated in FIG. **22** ends.

The above is a description of the modification #1.

(2-4) Modification #2 (Combined Use B of Non-Map-Using System)

Next, another modified example (modification #2) of the second embodiment will be described with reference to FIGS. **23** and **24**. The modification #2 relates to a system that sets, upon generating a map, a system selection flag indicating whether an evaluation value J of a solid is less than a threshold Th or greater than the threshold Th, and selects a color correction method using a system selection map associating the system selection flag and a solid number.

The system selection flag is a flag that is referred to when selecting a method for color correction. The non-map-using system is selected when the system selection flag is 1, and the color correction method using maps is selected when the system selection flag is 0. Upon applying the modification #2, the evaluation process and the solid selection process performed by the table creation unit **111** are modified as illustrated in FIG. **23**. Further, upon applying the modification #2, the solid determination process performed by the image correction unit **112** is modified as illustrated in FIG. **24**. These processes will be described below.

(Evaluation and Solid Selection)

The evaluation process and the solid selection process according to the modification #2 will be described with reference to FIG. **23**. FIG. **23** is a flowchart illustrating the flow of the evaluation process and the solid selection process according to the other modified example (modification #2) of the second embodiment. The processes illustrated in FIG. **23** are performed by the evaluation unit **132** and the solid selection unit **133**.

As illustrated in FIG. **23**, the evaluation unit **132** sets a minimum solid number parameter s_{min} for identifying a solid number having the smallest evaluation value to 0 (S**401**). Then, the evaluation unit **132** sets a minimum evaluation value parameter J_{min} used for calculating the smallest evaluation value to 0 (S**402**). Then, the evaluation unit **132** sets a solid number parameter s for specifying a solid number to 0 (S**403**). Note that steps S**401**, S**402**, and S**403** may be performed in any order.

Then, the evaluation unit **132** calculates an evaluation value J_s of the solid with the solid number s (S**404**). For example, the evaluation unit **132** calculates the evaluation value J_s based on the above expression (6) or (7). Then, the solid selection unit **133** determines whether the solid number s is on the solid number list (S**405**). If the solid number s is on the solid number list, the process proceeds to step S**408**. On the other hand, if the solid number s is not on the solid number list, the process proceeds to step S**406**.

When the process proceeds to step S**406**, the solid selection unit **133** compares the minimum evaluation value parameter J_{min} and the evaluation value J_s, and determines whether the minimum evaluation value parameter J_{min} is greater than the evaluation value J_s (S**406**). If the minimum evaluation value parameter J_{min} is greater than the evaluation value J_s, the process proceeds to step S**407**. On the other hand, if the minimum evaluation value parameter J_{min} is not greater than the evaluation value J_s, the process proceeds to step S**408**.

When the process proceeds to step S**407**, the solid selection unit **133** sets the minimum evaluation value parameter J_{min} to J_s, and sets the minimum solid number parameter s_{min} to s (step S**407**). When the operation of step S**407** completes, the process proceeds to step S**408**. When the process proceeds to step S**408**, the solid selection unit **133** determines whether s is the maximum value of the solid number (S**408**). When s is the maximum value of the solid number, the process proceeds to step S**410**. On the other hand, if s is not the maximum value of the solid number, the process proceeds to step S**409**.

When the process proceeds to step S**409**, the solid selection unit **133** performs update processing that increments s by 1 (S**409**). When the operation of step S**409** completes, the process returns to step S**404**. When the process proceeds to step S**410**, the solid selection unit **133** adds the solid number s_{min} to the selected-solid number list (S**410**). Then, the solid selection unit **133** compares J_{min} with the threshold Th, and sets a system selection flag corresponding to the solid number s_{min} in accordance with the comparison result (S**411**).

For example, the solid selection unit **133** sets the system selection flag to 1 if J_{min} is greater than the threshold Th, and sets the system selection flag to 0 if J_{min} is less than the threshold Th. The threshold Th is set in advance. The set system selection flag is stored in association with the solid number in the system selection map. The system selection map is input to the table creation unit **111**. When the operation of step S**411** completes, a series of operations illustrated in FIG. **23** ends.

The above is a description of the evaluation process and the solid selection process according to the modification #2.

(Solid Determination)

The following describes the solid determination process according to the modification #2 with reference to FIG. **24**. FIG. **24** is a flowchart illustrating the flow of the solid determination process according to the other modified example (modification #2) of the second embodiment. The process illustrated in FIG. **24** is performed by the solid determination unit **142**.

As illustrated in FIG. **24**, the solid determination unit **142** sets the system flag to 0 (S**421**). Further, the solid determination unit **142** receives an input of a solid count c representing the number of candidate solids (S**422**). Further, the solid determination unit **142** receives a solid number s_j (j=1, . . . , c) identifying each candidate solid (S**423**). Note that when c is 0, the solid number s_j (j=1, . . . , c) is not input.

Then, the solid determination unit **142** determines whether c is 0 (S**424**). If c is 0, the process proceeds to step S**430**. On the other hand, if c is not 0, the process proceeds to step S**425**. When the process proceeds to step S**425**, the solid determination unit **142** determines whether c is 1 (S**425**). If c is 1, the solid determination unit **142** selects the solid with the solid number s_1, and the process proceeds to step S**427**. On the other hand, if c is not 1, the process proceeds to step S**426**.

When the process proceeds to step S**426**, the solid determination unit **142** selects a solid containing the input color from solids with solid numbers s_j (j=1, . . . , c) (S**426**). When the operation of step S**426** completes, the process proceeds to step S**427**. When the process proceeds to step S**427**, the solid determination unit **142** determines the selected solid as a solid to be used for conversion of the input color (S**427**).

Then, the solid determination unit **142** determines whether the system selection flag corresponding to the solid determined in step S**427** is 1 (S**428**). If the system selection flag corresponding to the solid determined in step S**427** is 1, the process proceeds to step S**429**. On the other hand, if the system selection flag corresponding to the solid determined in step S**427** is 0, the process proceeds to step S**430**.

When the process proceeds to step S**429**, the solid determination unit **142** determines whether the solid determined in step S**427** contains the input color (S**429**). If the solid determined in step S**427** contains the input color, a series of operations illustrated in FIG. **24** ends. On the other hand, if the solid determined in step S**427** does not contain the input color, the process proceeds to step S**430**.

When the process proceeds to step S**430**, the solid determination unit **142** sets the system flag to 1 (S**430**). The non-map-using system is selected when the system flag is 1, and a color correction method using maps is selected when the system flag is 0. When the operation of step S**430** completes, a series of operations illustrated in FIG. **24** ends.

The above is a description of the solid determination process according to the modification #2.

The above is a description of the modification #2.

(2-5) Appendix (Example of Non-Map-Using System)

An example of the above-mentioned non-map-using system will now be described with reference to FIGS. **25** through **30**. Note that color correction processing according to the non-map-using system is performed by the conversion unit **143**.

In the following description, as illustrated in FIG. **25**, the coordinates of the input color are represented by (r, g, b), and the coordinates of N reference colors are represented by $\{(r_n, g_n, b_n), n=1, \ldots, N\}$. FIG. **25** illustrates an example of the non-map-using system applicable to the modified examples (modifications #1 and #2) of the second embodiment.

Further, a reference color located closest to the input color in the color space is referred to as a "specified reference color" (or a "reference color of class 1"), and the coordinates of the specified reference color are represented by (r_m, g_m, b_m). Further, a reference color other than the specified reference color is referred to as a "non-specified reference color" (or a "reference color of class 2"), and the coordinates of the non-specified reference color are represented by (r_n, g_n, b_n) $(n \neq m)$. A process according to the non-map-using system will be described below.

(General Flow of Process)

The general flow of the process according to the non-map-using system will be described with reference to FIG. **26**. FIG. **26** is a first diagram illustrating the flow of the process according to the non-map-using system applicable to the modified examples (modifications #1 and #2) of the second embodiment. The process illustrated in FIG. **26** is performed by the conversion unit **143**.

As illustrated in FIG. **26**, the conversion unit **143** classifies the reference colors into a specified reference color and non-specified reference colors, and selects one of the non-specified reference colors (S**501**). Then, the conversion unit **143** generates conversion information to be used for color correction of the input color, by interpolation based on the non-specified reference color selected in step S**501** and the specified reference color (S**502**). Then, the conversion unit **143** calculates a weight to the non-specified reference color (S**503**). Note that in the case where the weight is not used in the subsequent operation, the operation of step S**503** may be omitted.

The conversion unit **143** repeats the operations of steps S**501** through S**503** for all the non-specified reference colors. By repeating these operations, N−1 pieces of conversion information to be used for color conversion of the input color are obtained. The conversion unit **143** consolidates the N−1 pieces of conversion information, and performs color correction of the input color based on the consolidated conversion information (S**504**). When the operation of step S**504** completes, a series of operations illustrated in FIG. **26** ends.

(Reference Color Selection)

The process of step S**501** will now be further described with reference to FIG. **27**. FIG. **27** is a second diagram illustrating the flow of the process according to the non-map-using system applicable to the modified examples (modifications #1 and #2) of the second embodiment.

As illustrated in FIG. **27**, the conversion unit **143** receives an input of an input color (r, g, b) (S**511**). Further, the conversion unit **143** receives an input of reference colors $\{(r_n, g_n, b_n), n=1, \ldots, N\}$ (S**512**). Then, the conversion unit **143** selects a reference color (r_m, g_m, b_m) closest to the input color (r, g, b) (S**513**).

Then, the conversion unit **143** sets the reference color selected in step S**513** as a specified reference color (S**514**). Then, the conversion unit **143** sets reference colors other than the specified reference color as non-specified reference colors (S**515**). When the operation of step S**515** completes, a series of operations illustrated in FIG. **27** ends.

Note that the conversion unit **143** may limit the non-specified reference colors to be used for the subsequent operations. For example, the conversion unit **143** may set a reference color whose distance to the input color is less than a predetermined threshold Th_1 as a non-specified reference color. In this case, in the operation of step S**515**, the conversion unit **143** selects a reference color that satisfies the condition given by expression (10) below, and sets the reference color as a non-specified reference color. Note that | . . . | is a norm representing the size of a vector.

$$|(r_n-r_m,g_n-g_m,b_n-b_m)|<Th_1 \tag{10}$$

The above is a description of the process of step S**501**.

(Interpolation)

The process of step S**502** will now be further described with reference to FIG. **28**. FIG. **28** is a third diagram illustrating the flow of the process according to the non-map-using system applicable to the modified examples (modifications #1 and #2) of the second embodiment.

As illustrated in FIG. **28**, the conversion unit **143** receives an input of an input color (r, g, b) (S**521**). Further, the conversion unit **143** receives an input of a specified reference color (r_m, g_m, b_m) (S**522**). Further, the conversion unit **143** receives an input of non-specified reference colors {(r_n, g_n, b_n), n≠m} (S**523**).

Then, the conversion unit **143** calculates parameters p_n and q_n that are used for calculating an interpolation conversion amount to be used for interpolation of the input color (S**524**). Then, the conversion unit **143** calculates an interpolation conversion amount (s_{rn}, s_{gn}, s_{bn}), using the parameters p_n and q_n calculated in step S**524** (S**525**). When the operation of step S**525** completes, a series of operations illustrated in FIG. **28** ends. The operations of steps S**524** and S**525** will be further described below. In the following description, FIG. **25** will be referred to as needed.

When calculating the interpolation conversion amount, the conversion unit **143** calculates a line segment connecting a non-specified reference color and a specified reference color in the color space, and calculates the interpolation conversion amount using a point (x_n) on the line segment closest to the input color. The point x_n closest to the input color is obtained by performing an orthographic projection of the input color onto the line segment. That is, in geometric terms, the point where a perpendicular line from the input color to the line segment intersects the line segment is the above-described point x_n (see FIG. **25**).

A point on a line segment connecting the non-specified reference color (r_n, g_n, b_n) and the specified reference color (r_m, g_m, b_m) is represented by $w(p_n)$. Then, $w(p_n)$ is given by expression (11) below, where p_n is a parameter. Further, v_n in expression (11) below is defined by expression (12) below.

$$w(p_n)=\begin{bmatrix} r_s \\ g_s \\ b_s \end{bmatrix}+p_n\cdot v_n, \tag{11}$$

$$v_n=\begin{bmatrix} r_{1s}-r_{0s} & r_{2s}-r_{0s} & r_{3s}-r_{0s} \\ g_{1s}-g_{0s} & g_{2s}-g_{0s} & g_{3s}-g_{0s} \\ b_{1s}-b_{0s} & b_{2s}-b_{0s} & b_{3s}-b_{0s} \end{bmatrix}\begin{bmatrix} k_1 \\ k_2 \\ k_3 \end{bmatrix}+\begin{bmatrix} r_{0s} \\ g_{0s} \\ b_{0s} \end{bmatrix}$$

$$v_n=\frac{1}{l_n}\begin{bmatrix} r_n-r_m \\ g_n-g_m \\ b_n-b_m \end{bmatrix} \tag{12}$$

Here, v_n defined by the above expression (12) is a unit vector indicating the direction from the specified reference color (r_m, g_m, b_m) to the non-specified reference color (r_n, g_n, b_n). Further, l_n is defined by expression (13) below, and represents the distance between the specified reference color (r_m, g_m, b_m) and the non-specified reference color (r_n, g_n, b_n). Note that if $0\le p_n\le l_n$, then the point x_n obtained by projecting the input color onto the above-described line is located on the line segment connecting the specified reference color (r_m, g_m, b_m) and the non-specified reference color (r_n, g_n, b_n).

The coordinates of the point x_n are given by expression (14) below, where u_n is a unit vector from the point x_n to the input color. The vector u_n and the parameter q_n in expression (14) below are given by expressions (15) through (19), where superscript T denotes the transpose of a vector, and the parameter q_n is the distance from the input color to the point x_n. The processing up to this point corresponds to the operation of step S**524**.

$$l_n=\sqrt{(r_n-r_m)^2+(g_n-g_m)^2+(b_n-b_m)^2} \tag{13}$$

$$(r_m, g_m, b_m)+q_n\cdot u_n \tag{14}$$

$$(r-r_m, g-g_m, b-b_m)^T=p_n\cdot v_n+q_n\cdot u_n \tag{15}$$

$$p_n=(r-r_m, g-g_m, b-b_m)\cdot v_n \tag{16}$$

$$u_n=\frac{1}{y_n}\{(r_n-r_m, g_n-g_m, b_n-b_m)^T-p_n\cdot v_n\} \tag{17}$$

$$y_n=|(r-r_m, g-g_m, b-b_m)^T-p_n\cdot v_n| \tag{18}$$

$$q_n=(r-r_m, g-g_m, b-b_m)\cdot u_n \tag{19}$$

The following describes interpolation processing of the point x_n. Here, conversion of the specified reference color (r_m, g_m, b_m) is given by expression (20) below, and conversion of the non-specified reference color (r_n, g_n, b_n) is given by expression (21) below. In this case, conversion at the point x_n is given by expression (22) below using liner interpolation. The conversion unit **143** calculates conversion (s_{rn}, s_{gn}, s_{bn}) as the interpolation conversion amount in the operation of step S**525**. The conversion unit **143** calculates the interpolation conversion amount for all the non-specified reference colors in the same manner.

$$(t_{rm},t_{gm},t_{bm})=(r_{ms}-r_m,g_{ms}-g_m,b_{ms}-b_m) \tag{20}$$

$$(t_{rn},t_{gn},t_{bn})=(r_{ns}-r_n,g_{ns}-g_n,b_{ns}-b_n) \tag{21}$$

$$(s_{rn},s_{gn},s_{bn})=p_n\cdot(t_{rn},t_{gn},t_{bn})+(1-p_n)\cdot(t_{rm},t_{gm},t_{bm}) \tag{22}$$

The above is a description of the process of step S**502**.

(Weight Calculation)

The process of step S**503** will now be further described with reference to FIG. **29**. FIG. **29** is a fourth diagram illustrating the flow of the process according to the non-map-using system applicable to the modified examples (modifications #1 and #2) of the second embodiment.

As illustrated in FIG. **29**, the conversion unit **143** receives an input of the interpolation conversion amount (s_{rn}, s_{gn}, s_{bn}) for a pair of the specified reference color (r_m, g_m, b_m) and the non-specified reference color (r_n, g_n, b_n) (a pair of m and n) (S**531**). Here, n=1, . . . , N (n≠m). Then, the conversion unit **143** calculates a weight, for each of the non-specified reference colors (S**532**). When the operation of step S**532** completes, a series of operations illustrated in FIG. **29** ends. The operation of step S**532** will be further described with reference to three examples. Note that the weight to the non-specified reference color (r_n, g_n, b_n) is represented by w_n.

First Example

Weight Calculated Taking Interpolation into Account

The first example relates to a method that calculates the weight w_n which restricts such that only the interpolation conversion amount in the case where the point x_n is located on the segment connecting the specified reference color (r_m, g_m, b_m) and the non-specified reference color (r_n, g_n, b_n) is used for color correction of the input color. In the case where this method is applied, the weight w_n is given by expression (23) below. In this case, the conversion unit **143** calculates the weight w_n based on expression (23) below. Note that the conversion unit **143** calculates the parameter z used in the operation of step **S504** based on expression (24) below.

$$\begin{cases} w_n = 1 & 0 \le p_n \le 1 \\ w_n = 0 & p_n > 1,\ p_n < 0 \end{cases} \tag{23}$$

$$z = \sum_{n=1,n\neq m}^{N} w_n \tag{24}$$

Second Example

Weight Calculated Taking Length of Perpendicular Line into Account

The second example relates to a method that calculates the weight w_n in accordance with the magnitude of the parameter q_n representing the length of the perpendicular line from the input color to the point x_n. In the case where this method is applied, the weight w_n is given by expression (25) below. In this case, the conversion unit **143** calculates the weight w_n based on expression (25) below. Further, the conversion unit **143** calculates the parameter z used in the operation of step **S504** based on the above expression (24).

$$w_n = \frac{1}{q_n^2} \tag{25}$$

Third Example

Weight Calculated Taking Distance Between Reference Colors into Account

The third example relates to a method that calculates the weight w_n in accordance with the distance l_n between the specified reference color (r_m, g_m, b_m) and the non-specified reference color (r_n, g_n, b_n). It is assumed that the greater the distance l_n is, the less the interpolation of the input color is affected by the non-specified reference color (r_n, g_n, b_n). Accordingly, the conversion unit **143** calculates the weight w_n based on expression (26) below. Further, the conversion unit **143** calculates the parameter z used in the operation of step **S504** based on the above expression (24).

$$\begin{cases} w_n = 1 & l_n > Th_l \\ w_n = 0 & l_n \le Th_l \end{cases} \tag{26}$$

The above is a description of the process of step **S503**.

(Consolidation)

The process of step **S504** will now be further described with reference to FIG. **30**. FIG. **30** is a fifth diagram illustrating the flow of the process according to the non-map-using system applicable to the modified examples (modifications #1 and #2) of the second embodiment.

As illustrated in FIG. **30**, the conversion unit **143** receives an input of the interpolation conversion amount (s_{rn}, s_{gn}, s_{bn}) for a pair of the specified reference color (r_m, g_m, b_m) and the non-specified reference color (r_n, g_n, b_n) (a pair of m and n) (S**541**). Here, n=1, . . . , N (n≠m). Then, the conversion unit **143** consolidates the interpolation results (interpolation conversion amounts calculated for the respective non-specified reference colors) (S**542**). When the operation of step S**542** completes, a series of operations illustrated in FIG. **30** ends. The operation of step S**542** will be further described below.

For example, in the case of using the weight w_n (n=1, . . . , N, n≠m) described as the first example and the parameter z, the conversion unit **143** consolidates the interpolation conversion amounts based on expression (27) below, and calculates conversion (s_r, s_g, s_b) for the input color. Similarly, in the case of using the weight w_n (n=1, . . . , N, n≠m) described as the second and third examples and the parameter z, the conversion unit **143** consolidates the interpolation conversion amounts based on expression (27) below.

$$(s_r, s_g, s_b) = \frac{1}{z}\sum_{\substack{n=1 \\ n\neq m}}^{N} w_n(s_m, s_{gn}, s_{bn}) \tag{27}$$

(Taking into Account Plural Types of Weights)

Two or more of the weights w_n (n=1, . . . , N, n≠m) described in the first through third examples may be used in combination. For example, the conversion unit **143** consolidates the interpolation conversion amounts based on expression (28) below, where $w_n^{(1)}$ is the weight w_n according to the first example, $w_n^{(2)}$ is the weight w_n according to the second example, and $w_n^{(3)}$ is the weight w_n according to the third example. Note that the parameter z is given by expression (29) below. When $w_n^{(j)}$ is 1 for all the n-values, expression (28) below is an expression that does not take into account the weight w_n according to a j-th example.

$$(s_r, s_g, s_b) = \frac{1}{z}\sum_{\substack{n=1 \\ n\neq m}}^{N} w_n^{(1)} w_n^{(2)} w_n^{(3)}(s_m, s_{gn}, s_{bn}) \tag{28}$$

$$z = \sum_{n=1,n\neq m}^{N} (w_n^{(1)} w_n^{(2)} w_n^{(3)}) \tag{29}$$

(Omitting Calculation of Weight)

In the case of not taking into account the weight w_n and omitting the process of step **S503**, the conversion unit **143** consolidates the interpolation conversion amounts based on expression (30) below. That is, the conversion unit **143** calculates conversion (s_r, s_g, s_b) for the input color by obtaining the average of N−1 interpolation conversion amounts.

$$(s_r, s_g, s_b) = \frac{1}{N-1}\sum_{\substack{n=1 \\ n\neq m}}^{N} (s_m, s_{gn}, s_{bn}) \tag{30}$$

The above is a description of the process of step **S504**.

The above is a description of the example of the non-map-using system.

The above is a description of the second embodiment. By applying the technique of the second embodiment, it is possible to perform high-accuracy color correction based on volume interpolation using maps at high speed. Further, by applying modifications described above, high-accuracy color correction using maps is realized in the case where the input color is contained in a solid whose vertices are defined by reference colors. Further, even in the case where the input color is not contained in any solid, color correction of the input color is realized directly using reference colors.

The techniques described above are applicable to color correction processing performed in, for example, printers, scanners, cameras, or displays used for personal computers and smart phones.

According to the present invention, it is possible to perform interpolation processing of an input color based on reference colors that are arbitrarily set in a color space.

All examples and conditional language provided herein are intended for the pedagogical purposes of aiding the reader in understanding the invention and the concepts contributed by the inventor to further the art, and are not to be construed as limitations to such specifically recited examples and conditions, nor does the organization of such examples in the specification relate to a showing of the superiority and inferiority of the invention. Although one or more embodiments of the present invention have been described in detail, it should be understood that various changes, substitutions, and alterations could be made hereto without departing from the spirit and scope of the invention.

What is claimed is:

1. An information processing apparatus comprising:

a memory configured to store a table including information on regions respectively occupied by a plurality of solids whose vertices are defined by a plurality of reference colors that are set in a color space, each of the solids having an evaluation value less than a setting value, the evaluation value decreasing as a length of edges thereof decreases, the solids being arranged such that faces thereof do not cross each other; and

a processor configured to perform a procedure including:

specifying a solid containing an input color with use of the table, and performing interpolation processing of the input color with use of the reference colors corresponding to the vertices of the specified solid, wherein

each of the solids is a triangular pyramid;

the evaluation value decreases as the length of each of the edges connecting four vertices of the triangular pyramid decreases.

2. The information processing apparatus according to claim **1**, wherein:

the table is a look-up table that associates positional information for identifying a region in the color space and identification information for identifying each of the solids.

3. The information processing apparatus according to claim **1**, wherein:

the table includes maps, one for each coordinate axis of the color space, each of the maps representing a correspondence relationship between each value on the coordinate axis and the solids; and

the processor specifies the solid containing the input color with use of the maps.

4. The information processing apparatus according to claim **1**, wherein:

the memory stores conversion information for converting a position in the color space identified from each of the reference colors contained in an image into a position in the color space that is set for the reference color; and

the processor calculates a conversion amount for the input color, based on the conversion information.

5. The information processing apparatus according to claim **1**, wherein when the input color is not contained in any of the plurality of solids, the interpolation processing of the input color is performed based on the reference color located near the input color in the color space.

6. The information processing apparatus according to claim **1**, wherein when the evaluation value of the solid containing the input color is greater than a set threshold, the interpolation processing of the input color is performed based on the reference color located near the input color in the color space.

7. A non-transitory computer-readable storage medium storing a computer program that causes a computer to perform a procedure comprising:

reading, by a processor, from a memory, a table including information on regions respectively occupied by a plurality of solids whose vertices are defined by a plurality of reference colors that are set in a color space, each of the solids having an evaluation value less than a setting value, the evaluation value decreasing as a length of edges thereof decreases, the solids being arranged such that faces thereof do not cross each other; and

specifying, by the processor, a solid containing an input color with use of the table, and performing interpolation processing of the input color with use of the reference colors corresponding to the vertices of the specified solid, wherein

each of the solids is a triangular pyramid;

the evaluation value decreases as the length of each of the edges connecting four vertices of the triangular pyramid decreases.

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